DID MAN CREATE GOD?

Is Your SPIRITUAL BRAIN at Peace with Your THINKING BRAIN?

DAVID E. COMINGS, M.D.

to

Sally — for being herself

Karen — whose wonderful spirituality gave me the idea to write this book

and

Jim — whose encouragement made it happen

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by

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Cover illustration: Michelangelo's depiction of the creation of man in the chapter of Genesis on the ceiling of the Sistine Chapel 1508-1512.

Did Man Create God?

Table of Contents

Preface—About Reading This Book

This book is intended for all inquisitive readers who are interested in why humans are such a spiritual species; whether Intelligent Design is a valid alternative to Darwinian evolution; whether our sacred books were written by man or by God; whether God created man or man created God; whether man made up the theory of God as our creator and protector; and whether our rational thinking brain can live in peace with our spiritual brain.

It is written for both those who are well acquainted with many aspects of science and those who are not. For the latter I have kept the scientific jargon to a minimum and defined or explained any terminology used. While a high school-level knowledge of biology would be helpful, the reader with no background in biology at any level can still read and understand this book. For those whose first reaction is, "Wow, over 650 pages!", I have sprinkled summaries of all of the important points in **bold** text throughout the book. If a chapter repeats what you already know or bores or overwhelms you, just skip to the **bold summary** and go on. *One could obtain the essence of the whole book in a very short time by just reading these summaries.* If you wish to understand the reasoning and evidence behind the bold summaries, read the full chapter.

Introduction

When I was in grade school I was very interested in all aspects of science. My father was a professor of chemical engineering at the University of Illinois and my mother was a bright independent thinker. They both encouraged my interests and attempted to answer each of my many questions. I collected rocks, minerals, and fossils, and stuffed every dead animal I could find. I found a set of *The Book of Knowledge* encyclopedias in our family library and read about all the geological epochs—Cambrian, Ordovician, Silurian, all the way to the Pleistocene. Each had a separate chapter, and as I progressed from one to the next I marveled at the unfolding evolution of life on earth. Darwin's theory of evolution by natural selection is a natural belief system that stayed with me my entire life. My parents, who were Presbyterian at the time, brought me to Sunday school and then to church whenever they were forceful enough to counter my pleas of "Do I have to?" Getting dressed up in a suit and tie on a beautiful Sunday morning when there were a thousand more interesting things to do seemed like a unique form of parentally induced torture. Even if we only went to church once or twice a month, it was taken for granted that the religious instruction I received was sinking in and that I believed in God. For a time, this was true. In Sunday school, although we discussed the book of Genesis, I lived in a university town where virtually everyone believed in Darwinism and most of us viewed the Genesis story as an interesting metaphor for the creative power of God. No one suggested we should take the seven days for creation literally.

By the time I was in fourth grade I had finished all the chapters on paleontology, read parts of Darwin's *The Origin of Species* and all the books I could find in the local library on astronomy, geology, archeology and other "-ologies." I remember to this day lying on my bed in my room, surrounded by shelves full of my collections of rocks and fossils, stuffed birds, and a reconstructed cat skeleton. As a mental exercise I slowly worked my way back down the evolutionary ladder from man to earlier and earlier forms of life. I eventually reached the long period of time when the earth was populated only by single cells without a nucleus—the bacteria. This flow of evolving life forms seemed so logical that there was no need for the hand of God to help the process over the rough spots. No need for a God of the gaps.

I also had read enough about astronomy to be able to take the process back further and further to the creation of the universe from clouds of gas. This was before modern cosmology and the Big Bang theory had been proposed, but the trend was the same—the whole complex universe and all life on earth evolved from more primitive precursors. By running the tape backwards one ended up with those simple

precursors. It then occurred to me, lying there in the dark long after my bedtime, that the next question was, where did these simple precursors come from? There were two possibilities: they came from some form of matter or energy that was even simpler, or God made them. I had not yet heard of Occam's razor, the concept in science that the simplest explanation is usually the correct one. However, it seemed inherently reasonable that the simplest explanation was the best. To believe that God made the gases left a huge remaining question—Who Made God? God is the most complex concept or entity in all human thought, capable of incredible feats, pervasive, omnipresent, aware of our every thought and action, able to listen to, sort out and possibly act on the prayers of billions of people on a daily, hourly or even second-by-second basis. When considering primitive gases or God, based on the principle of Occam's razor, there was never an easier choice. Primitive gas was clearly the winner in the simplicity race. The question of "Who created God?" was then fairly simple—man created God. People in different parts of the world tailored God to conform to the unique aspects of their own culture and history, resulting in a wide range of different beliefs and religions.

Having come to this conclusion in the summer before fifth grade, my first thought was, "Now I am really in deep trouble." God is going to be very upset with me for doubting Him. Would He retaliate in some subtle way but cover His tracks so no one could really blame Him, like making me fall off my bicycle or get an F in my next math exam? "OK," I said to Him. "I will give you one week to do something about what I was thinking. If I don't hear back in a week, I will be forced to conclude that I was right. You don't really exist." Nothing happened. This issue was clearly not so simplistic that I would not believe in God just because I did not get an F in math the following week. But I was relieved to find that if He did exist, He must be a kind, understanding, and non-punitive God.

Since that evening many further developments in a range of scientific disciplines have strengthened my early conclusions and I have continued to believe that man created God. I have also continued to marvel at all the questions this answered that my theistic friends who believed in God were still struggling with. Foremost among these, if God was such a benevolent and loving being, how could He let such bad things happen to humans, such as the world war we were then in the midst of? If man created God, this was a non-issue. It made much more sense to believe we were in this universe alone and what we made of our lives, our country, and our world—was of our own doing. We should not screw it up, because no one was going to come to our rescue if we did.

My next hurdle was to tell my parents, especially my mother, of my conclusions about God. I waited several years before summoning the courage to do so. When I finally told her, the reaction was, "David, you don't really believe that." When I assured her that I did, I think she simply entered into a state of quiet denial and after that we never discussed it again. My father was nonplussed. Being well versed in science, I suspected that secretly he felt I had a valid point. By the time I was in medical school, if I went to church at all it was to meet girls. I went to the Unitarian church, where

theists, agnostics, and atheists could all commune together in harmony. Long after I moved from home I was heartened to find that both my parents had joined the Unitarian church. I never subsequently discussed with them which of the above three categories they fit in, but I suspected it was the agnostic group.

When I was in high school, a good friend invited me to spend several weeks of a summer vacation with him and his parents in a cabin on the Gun Flint Trail in northern Minnesota. Being an amateur mammalogist, I immediately went to my *Field Guide of North American Mammals* to see what I might encounter. I was intrigued to find that the pigmy shrew *(Microtus agresti)*, both the smallest and the rarest of the North American mammals, had habitats in the area. Thus, I included in my suitcase a dozen mousetraps and a set of my mammal-skinning tools. A few days after arriving, I placed the traps near the water of a distant lake. I never dreamed that I would catch one, but the hunt for such a rare species was exciting. To my great astonishment, over the time I was there I caught five of these unique creatures. Since they were supposed to be rare, I felt five was enough. I skinned them and stuffed them with cotton to make what are called "study skins." I kept the skulls since the definitive identification of the species was based on specific characteristics of the teeth. Since they were so small, the muscles quickly dried, forming a mummified skull.

The best way to remove the muscle tissue from these skulls was to place them in a box with carrion beetles that feed on the flesh, leaving a pristinely clean skull. I did not have any carrion beatles, so several months after I returned home I went to visit the head of the department of mammalogy and curator of the Natural History Museum at the University of Illinois. I will refer to him as "George." I walked into his office and told him that I had five *Microtus agresti* skulls and proposed that if he would allow me to put them in his box of carrion beetles, I would let him keep a couple of the skulls and skins for the museum. I told him I was sure they were *Microtus agresti* because they had the characteristic tooth patterns of this species. He looked at me as though I was an alien who had just dropped down from a space ship. Here I was, a gangly teenager telling this head of the mammalogy department that I had not just one, but five skulls of the rarest and smallest mammal in the United States, while he had none. There was an unmistakable expression on his face that was a cross between total disbelief and a desire to show this young upstart that if I thought he was going to pass the skulls of a common house mouse off as *Microtus agresti* skulls he was going to quickly put me in my place and usher me out the door. He picked up a hand lens from his desk and began to examine the teeth. One of the greatest pleasures of my young life was to watch the smirk disappear, to be replaced by a jaw-dropping stare. He said, "These are *Microtus agresti;* where did you get them?" After I told him the story, he said he would be glad to clean the skulls up for me. To my utter astonishment, he next told me that he and two graduate students were planning a month-long expedition to New Mexico next summer. They could use some help and would I be interested in joining them. I agreed on the spot. By now you must be wondering, where is all of this going and what does this have to do with the issue of *Did Man Create God*? Be patient.

When next summer came, I did indeed join the group. They were interested in examining the sub-species of *Peromyscus* and other small mammals in the mountains of New Mexico. Being young and daring, I climbed down into a very steep gorge one day and placed about 160 mousetraps along the streambed. Unfortunately, I was far more successful than I planned and ended up collecting over 110 mice. When I got back to camp they were all excited about this success. I assumed we would make study skins of a representative sample and throw out the rest. That was not to be. George said we had to stuff all 110. At a rate of six mice per hour per person, that translated into five hours of work just for my mice. We would be working well into the night. We all sat at workbenches and talked while we worked. By midnight, the conversation turned from science to religion. Since I was with a group of fellow scientists I felt comfortable in telling them about my evening of revelation when I was in grade school, and how I felt that the only thing that made sense for me was that man created God, rather than the other way around. Instead of the "Amens" I expected from this scientifically sophisticated group, the mood instantly changed. My proud pronouncements went over like a child who had just yelled out a string of obscenities in church. To call this chill hostility was putting it mildly. Not a single one of the three scientists agreed with me, and each of them reacted with animosity and anger. We spent the rest of the evening silently finishing our job and went to bed. The next morning the silence continued through breakfast. We then went back into the field I was given the task of digging a hole, to what purpose I have long forgotten. In the process I got some dirt on George's shoe. He immediately smacked me hard in the face with the flat of his hand, sending me reeling backward to the ground. None of us said anything, but we all knew this was not because I got some dirt on his shoes. To top it all off, I never got any of my *Microtus* skulls back.

From that episode I learned that people take their religious views very seriously, to the point of physically assaulting those who threaten their beliefs. Being a scientist and being trained in the scientific method does not automatically prevent a person from having a belief system that is often in conflict with rational scientific thinking. This was the start of my beginning to think about what is going on in the brains of humans which allows them to be capable of the rational thinking that has become the basis of a remarkable scientific revolution and simultaneously be capable of a spirituality and faith system that may be in total conflict with rational thought. This episode also taught me to choose wisely with whom I discussed my thoughts about God.

The next time I summoned the courage to discuss my religious insight was in college. My parents had moved to Lafayette, Indiana, because my father had gotten a new job as head of the department of chemical and metallurgical engineering at Purdue University. My mother, in her great wisdom, realized it would be difficult for me to start a new school as a senior where the other students had known each other for years. At the time I was attending University High School in Champaign, Illinois. She investigated and found that I needed only a few more credits to graduate. Two summer school courses later I entered the University of Illinois at age 16. To help make ends meet, I found a job in a rooming house that provided room and board in

exchange for my washing the breakfast and evening dishes. One evening after I had finished studying, I wandered into the room of a friend and a fellow dishwasher who was also the only other pre-medical student in the house. We sat talking for about an hour when the subject turned to religion. Since he was in pre-med and since we had become good friends, I thought he would be open to my views, and once again I opened my big mouth and began to relate my childhood revelation. After I completed the story his demeanor changed. He stared at me for a minute with hostile eyes, then flew across the room in a rage and started pounding on me. It took several others who happened to be in the hall to pull him off of me.

It always amazed me that I could sit and listen to others espouse their religious views for hours, respect them, and not get the slightest bit upset. By contrast, some would listen to my views for only a few minutes and fly into a rage. Why the difference? Perhaps others had never seriously questioned the beliefs they had been taught from childhood and were never exposed to anyone who presented a line of reasoning that potentially challenged those beliefs. If what I said was so outrageous that it made no sense, they would not feel challenged. However, if it did make some sense, suggesting their own life-long views might need some adjusting, it could indeed be threatening and engender anger and even rage.

After college I attended medical school at Northwestern University, then took my internship, internal medicine residency, and a fellowship in hematology at Cook County Hospital in Chicago. At the time I took hematology, Watson and Crick had just recently solved the structure of DNA; Vernon Ingram had just identified a single amino acid change in the hemoglobin molecule of children with sickle cell anemia, thus beginning the field of molecular medicine; and Marshall Nierenberg and Severo Ochoa were in the process of deciphering the genetic code. All of these extraordinarily exciting developments led me to take a second fellowship in human genetics with Arno Motulsky at the University of Washington in Seattle. I subsequently became the head of the department of medical genetics at the City of Hope National Medical Center in Southern California, where I stayed for 37 years.

I have enjoyed a wonderful career in human genetics. From 1968 until 1979 I was involved in both clinical genetics and basic research into human chromosome structure and DNA metabolism. In 1980 I undertook a major switch to become involved in the molecular and clinical genetics of human behavior especially relating to Tourette syndrome, attention deficit hyperactivity disorder (ADHD) and conduct disorder. Thus, my expertise is in genetics, human molecular genetics, neuroscience, and behavioral medicine. I was so involved in scientific writing that I never entertained thoughts of writing about religion and the subject of this book. However, several things happened in recent years compelling me toward this undertaking.

One reason I decided to write the book relates to the recent development of the Intelligent Design (ID) movement. After retiring from the City of Hope in 2002, I began to catch up on my reading in fields that were not directly related to medicine. One was James Hogan's book, *Kicking the Scared Cow,* [1] a compilation of chapters questioning some of the commonly accepted paradigms about a range of areas, one

of which was examining various aspects of Darwin's theory of evolution. This introduced me to the difference between the creationists and the ID creationists. The creationists object to Darwinism because they literally accept the Book of Genesis and claim the world is less than 10,000 years old. The ID creationists tend to accept that the world is in fact 4.5 billion years old and that some form of evolution occurred, but they have concerns about certain more complex aspects of Darwinian evolution. These objections led them to conclude that ultimately only a supreme being could have created the universe, the world, and all life. While not necessarily saying the force is God, most Intelligent Design enthusiasts are self-avowed fundamentalist Christians. Their position is that if something cannot be easily explained by current evolution science or if it seems too irreducibly complex to have evolved by natural selection, it must have been created by a supreme power. Later I found that Hogan took many of his objections about evolution from Jonathan Wells's book, *Icons of Evolution Science or Myth?*[2] Wells' book carried the teaser line: *Why much of what we teach about evolution is wrong.*

The objections of the Intelligent Design group are often seemingly reasonable questions about the Darwinian theory of evolution. While some of their points are little more than pickiness, some do not have trivial answers and some have also been points of concern by mainstream scientific evolutionists, including Darwin himself. However, as pointed out by Forrest and Gross in their book, *Creationism's Trojan Horse: The Wedge of Intelligent Design,*[3] Intelligent Design is little more than neo-creationism. Phillip Johnson, the founder of the movement stated,

> …we should affirm the reality of God by challenging the domination of materialism and naturalism in the world of the mind. With the assistance of many friends I have developed a strategy for doing this….We call our strategy *The Wedge.*[4]

By their definition, naturalism was any form of science that provided answers that excluded God as part of the explanation.[5] Their preference was theistic realism that assumes that God[6] brought the universe and all of its creatures into existence. The originators of the Intelligent Design movement stated they were,

> …unhappy with the polarized debate between biblical literalism and scientific materialism. We think a critical re-evaluation of Darwinism is both necessary and possible without embracing young-earth creationism.[3p18]

Disturbingly, not only are they dedicated to a neo-creationist agenda, but also to toppling the scientific method from its pedestal in Western culture and to contaminating the teaching of scientific biology in our schools. *The Wedge* approach is asking us to abandon sound scientific methods and reintroduce divine entities and miraculous "explanations" into theories and theorizing.[7p197,284] This is, in essence, a return to the Middle Ages. They then insist we teach this in our schools.

This would be a tragedy for the economy of both our country and the world. Economists have attributed more than half of the gains in gross national product and up to 85 percent of the gains in per capita income over the past several decades to advances in science and and technology. [11]

Science works best in a culture that welcomes challenges to prevailing ideas and matures the potential of all of its people. Scientific ways of thinking and of re-evaluationg one's views in light of new evidence help strengthen a democracy. [12]

From the perspective of a molecular geneticist, I found that many of the Intelligent Design concerns and objections were based on a profound ignorance of aspects of evolutionary theory and molecular genetics having to do with mutation rates, gene duplication, repetitious DNA, molecular evolution, molecular genetics of embryonic development, developmental genes, gene regulation, and others. One of the themes of this book is that the theory of evolution provides a more-than-adequate explanation for how life was created and evolved than does Intelligent Design.

Another reason for deciding to write this book came from recent developments in the field of cosmology. In my childhood musings, the furthest back I could take my evolutionary logic was to some vague, ancient, nebulous gases. What, if anything, could possibly be simpler than that? The latter half of the twentieth century saw impressive gains in our understanding of the universe, with findings relating to quantum mechanics, relativity, black holes, the accelerated expansion of the universe and most recently string theory and M theory. String theory suggests that all the major forces (gravity, electromagnetic, strong, and weak) and all the subatomic particles are formed by different lengths and levels of vibration of extraordinarily small strings of energy. String theory dramatically pushes back the boundaries for simpler precursors.

The recent decision by Judge Jones against the efforts of the ID community to attempt to promote the teaching of ID in the Dover, Pennsylvania schools was a remarkable victory for keeping the teaching of religion and creationism out of the schools. In part, the decision read,

> Both defendants and many of the leading proponents of ID make a bedrock assumption, which is utterly false. Their presupposition is that evolutionary theory is antithetical to a belief in the existence of a supreme being and to religion in general. Repeatedly in this trial, Plaintiffs' scientific experts testified that the theory of evolution represents good science, is overwhelmingly accepted by the scientific community, and that it in no way conflicts with, nor does it deny, the existence of a divine creator. [8]

Judge Jones characterized the attempt by the Dover School Board to introduce ID in the classroom as "breathtaking inanity." However, this has only slightly dampened the enthusiasm of the attempts to introduce ID and to destroy the teaching of the scientific method in schools. This decision heightened the

effort of creationists to advance their theories in other parts of the world. The best defense against the ID movement is to make available to parents, schools, and teachers information that allows them to intelligently counter many of the ID claims. This is covered in Part II of this book. Up to this point I thought of naming the book *Intelligent Answers to Intelligent Design.* However, this would only be part of the story.

The individuals who have formulated the ID movement, planned *The Wedge* strategy, and written the books, are bright people. As pointed out by Michael Shermer in his book, *How We Believe,*[9] most of the ID supporters themselves are well-educated, intelligent individuals. In addition, it has been estimated that over 95 percent of the world's population believe in a supreme power, a supernatural being. More specifically, in the United States a 1996 Gallup poll showed that 96 percent believed in God, 90 percent believed in heaven, 79 percent believed in miracles, 73 percent believed there was a hell, 72 percent believed in angels, and 65 percent believed the devil is real. Clearly communication or connection with God and a belief in the supernatural plays an important role in most people's lives.

This raises the question, "Are those of us who believe in the supremacy of rational thought and are atheists or agnostics, and would answer negatively to all of the above questions, missing something? Do non-believers know something that the others do not, or is it the other way around?" Humans have been endowed with a brain that contains two remarkable and unique abilities—the capability for complex, analytical reasoning and thought, and the capacity for spirituality or the need to feel connected to something larger and outside of oneself. I term these the rational brain and the spiritual brain. Are these two brains fundamentally in conflict with each other? The spiritual need is usually satisfied by believing in a superior force or being, most often called God, or an equivalent concept in different cultures, languages, and religions. As noted in the Gallup poll, this is often associated with a belief in a wide range of entities that our rational brain tells us cannot and do not exist. Thus, an equally important aspect of this story is to attempt to understand how and why *Homo sapiens*, a highly rational and uniquely intelligent species, also has a capability and apparent need to adopt systems of belief and faith that often place the spiritual brain in conflict with the rational brain. Both of these abilities must have been selected in the evolution of man, suggesting they both played a critical role in allowing humans to evolve and function in complex societies.

So why write this book? It may just make a lot of people mad like it did in the two experiences I related above. My purpose is not to make people angry or mad. It is to make them think and consider things they may have not previously considered. Since my professional background is firmly rooted in the science of basic and molecular genetics, neuroscience, and the biology and psychology of human behavior, and since I have written nearly 500 papers and abstracts and three books on these subjects, I felt I was as qualified as any to write about these issues.

Scores of philosophers, theologians and scientists over the centuries have agreed on one thing—it is impossible to prove the existence or non-existence of God. Thus,

it is not my purpose to be so bold as to attempt that. However, a different question, *Did Man Create God?* is clearly amenable to scientific inquiry. By this I refer to whether man himself was responsible for formulating the entity of an anthropomorphic God that for most people looks like a human being but has supernatural powers and under different names is the God for most of the world's major religions. Since one of the battlefields that the creationists have chosen is to question whether the man-made theory of evolution is correct, the question, *Did Man Create God?* could also be framed in terms of whether God is actually the result of a man-made Theory of God?* The essence of this book is well depicted in Michelangelo's Sistine Chapel fresco depicting the creation of man by the touching of the hand of God to the hand of man.

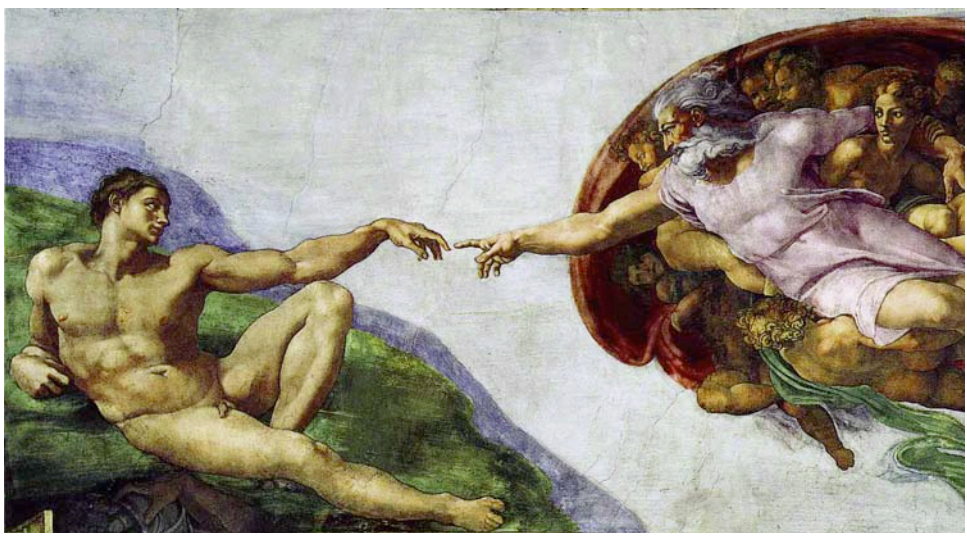

Figure 1. Michelangelo's Creation of Man in the Sistine Chapel.

The issue is, "Which way does the creativity flow? From God to man or from man to God?" The creation of God, embodied in the concept of the Theory of God, refers to a wide range of beliefs that include those about the creation of the universe, the earth, man and all other life on earth, the existence of a soul that lives on after we die, and the existence of an afterlife where we will be rewarded for leading a good and moral life.

Prior to the modern era, the Theory of God was the only viable explanation for many aspects of the natural world. An important added question is whether the sacred religious texts of the major religions, the Old Testament, the New Testament and the Qur'an (Koran), were also all essentially conceived and written by man rather than by God.

The questions "Did man create God?" and "Is the Theory of God a man-made

** A year-and-a-half after this introduction was written, Richard Dawkins also spoke of "The God Hypothesis" in his book,* The God Delusion. *[10] Two different sources for the same idea.*

theory?" are fundamentally different from the question "Does God exist?" It is perfectly possible that the answer to the question, "Did man create God?" is "Yes," and yet a God still exists that does not bear the slightest resemblance to the anthropomorphic, personal God of the world's major religions and a God that played no role in conceiving or writing the sacred texts. Thus, readers who have a strong belief in God should not be put off thinking I am trying to destroy that belief. I am not. I am, however, suggesting that they consider many of the issues covered in this book. As a result, if they ever had any personal doubts about their faith, if their own rational brains have objected to some of the things they have been taught from childhood, they may be able to adjust their beliefs just enough to make peace with their rational brain and to develop a *rational spirituality.*

It is also my purpose to point out that spiritual values and a belief in God or some transcendent force can be very satisfying and religion can accomplish wonderful things, but if man created God, perhaps we should not take ourselves so seriously that we get into fights, wars, and terrorism over whose God is the best God, and whose sacred text is the best text—they are all equally valid and equally able to satisfy the spiritual side of human existence. I also explore the issue of whether it is possible to reconcile the rational and spiritual parts of our brain. Is it possible to develop a satisfying spirituality that rewards the spiritual part of our brain and at the same time does not insult the rational part of our brain? Again, I believe the answer to that is yes. If that is possible then perhaps many of the negative aspects of religious beliefs could be eradicated while retaining all of the positive aspects.

This book is divided into seven parts.

Part I. Evolution. In premodern times, the concept of God the creator was central to providing man with an answer to the questions, "Where did we come from? Where did all the creatures on earth come from?" After Darwin's momentous studies on *The Origin of Species,* these questions had a rational, scientific answer. Species evolved by evolution and natural selection. However, the validity of the central role of evolution in the creation of man and earth's creatures is contested by both the young world creationists and proponents of an old world but with Intelligent Design.

This section is about Darwin's theory of evolution and its more modern versions such as neo-Darwinism, post-neo-Darwinism and evolutionary developmental genetics. Darwin wrote his ground-breaking *The Origin of Species* in 1859 before DNA and genes were identified, before the development of the field of population genetics, and before all of human DNA as well as the DNA of many other organisms were completely sequenced. Because of this lack of knowledge of modern genetics, there were many issues that were left unexplained in Darwin's original theory and even in neo-Darwinism formulated in the 1940s. Many aspects of the fossil record were incomplete in the mid-nineteenth century and to some extent, still are.

Part II. Intelligent Answers to Intelligent Design reviews some of the ID objections to Darwinian evolution. Based on quite recent aspects of molecular biology and paleontology, I show that despite the ID objections the basic Darwinian theory of evolution is still strong and vibrant. I hope to explain some fairly complex science in

a fashion that is easily understandable for the non-professional reader. This section has been presented in some detail because Intelligent Design arguments have been repeatedly used to validate the Theory of God. If readers are to come to their own conclusions about whether these arguments are valid or not, they need to know there are intelligent answers to all of the claims of the Intelligent Design creationists.

Part III. Cosmology. In premodern times, the concept of God the creator was also central to providing man with an answer to "Where did the earth come from? The sun? The stars? The universe?" If the reader thought that parts of Darwinian evolution were difficult to explain, some of the weirdness of quantum mechanics and string theory is even more so. Many of the new findings about astronomy and cosmology are highly relevant to issues of theology, religion, spirituality, and whether a God is necessary to create the universe. For example, does the Big Bang theory indicate that the universe was created from nothing? To many, the Big Bang proves the existence of God or at least the correctness of the Theory of God. Does it? Quantum theory shows that subatomic particles are instantaneously connected across the entire span of the universe. Some suggest this supports the concept of many Eastern religions that everything in the universe is interconnected. Does it? Does the combination of Darwinian evolution and cosmological evolution mean man is here by chance? Is he? If so does this affect our sense of purpose and the meaning of life? These and many additional spiritual implications of the new physics and modern cosmology are discussed.

Part IV. The Biology of the Rational and Spiritual Brain reviews the parts of the brain involved in consciousness, executive functions, rational and abstract thought, pleasure, social interactions, spirituality, meditation, self-healing, hope, happiness, and the biology of faith versus reason. Part IV shows that most of these traits and capabilities are hard-wired into the brain.

Part V. The Genetics of the Rational and Spiritual Brain reviews the role of genetic factors in bad behavior, altruism or good behavior, rational thought, and spirituality. When traits and capabilities are hard-wired into the brain this occurs because of the presence of a number of different genes interacting with each other and the environment.

Part VI. The Evolution of the Rational and Spiritual Brain. Complex, hard-wired, genetically regulated traits and capabilities do not just appear from nowhere. They are the result of evolution and natural selection over a period of thousands and millions of years. This section reviews the evidence relevant to the evolution of the rational brain (intelligence) and the spiritual brain (spirituality).

Part VII. Other Aspects of Spirituality and Religion. There are many additional aspects of human spirituality that are relevant to the question, "Did man create God?" This section reviews a number of these, including the origin of the major religions, mysticism, myth and ritual, and the role of psychedelics in spirituality and religion. In addition, the following questions are explored: Does God play favorites? Is one religion superior to another? Are there benefits to religion? Are there evils to religion? Is evil in the world incompatible with the existence of a kind and benevolent God? Are the sacred books literally true? and, Is God dead?

Part VIII. Summary. Parts I through VII have covered a wide range of complex subjects. Part VIII reviews these in relation to the subject of the book, *Did Man Create God?* Was man the author of the Theory of God? A range of issues are discussed concerning the meaning of life, whether morality or happiness is dependent on religion, and, most importantly, is it possible for you to develop a spiritual life that is not in conflict with your rational brain?

In recent decades there has been a dramatic increase in terrorism related to religious fundamentalism. This derives from the assumption that one religion is closer to being the true religion, one God is closer to being the true God, and one sacred religious book is better than another sacred religious book. All of these opinions are based on the assumption that God created man and that the sacred religious texts represent the spoken word of God. I challenge the reader to examine the validity of these assumptions.

While I personally do not believe in the existence of God, I am an unusual atheist in that I have the greatest respect for spirituality and many forms of religion. Some have referred to such individuals as "non-theists." Most Americans wrongly think that atheists are anti-theists, people who not only do not believe in God but also object to other's belief in God. A non-theist is simply "without a god-belief." In fact I argue that spirituality may have played such an important role in the evolution of man that without it we might not be here. Although I believe that a high level of spirituality does not automatically require that one also believe in God or be religious, I have respect for those whose level of spirituality has led them to believe in God and adopt religion as a means of expressing that belief. However, at the same time it is critical that people not hold the false beliefs that the universe, the earth, and all life could not have evolved without the helping hand of God, that one set of beliefs is superior to another, that one religion is better than another, or the false belief of fundamentalist religions that their sacred religious texts are the direct word of God and thus must be believed in their literal rather than in their metaphorical sense.

Knowledge of the biology of the spiritual brain helps us to understand why the majority of the human race believes in God. We owe it to ourselves and to the survival of the human race to understand where this need for spirituality comes from. We need to develop a *rational spirituality* that resists the adoption of rigid dogmatic religious systems and the belief in the superiority of one religion over another.

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Is God the true creator of everything that exists, or is God a product of the human imagination, real only in the minds of those who believe?

Phillip Johnson
Reason in Balance [1p7]

Science is the only self-correcting human institution, but it is also a process that progresses only by showing itself to be wrong.

Astronomer Allan Sandage

Part I

Evolution

Since ancient times man has struggled to understand where he and the world around him came from. For many centuries the most common answer to this question was that we are here because a supernatural power put us here. While some may have found this explanation less than totally satisfactory, it was not until the publication of Darwin's *The Origin of Species* in 1859 that a viable alternative explanation existed. Thus, it was now possible to move from the statement,

"God created man and all living things"
to
"Evolution created man and all living things."

While it is not necessarily valid or logical to move to the next step—thus God does not exist—in the minds of many, this was at least a thought to consider. Because of this, Darwinism has been incorrectly considered by many to be one of the greatest potential threats to all religions that are based on the assumption of the existence of a supreme being that created heaven and earth. Because of the importance of the theory of evolution to the theme of this book, I have devoted Part I and II to the subject. Part I reviews Darwin's theory of evolution, using mostly his own words. Since the theory has grown to be more advanced and complex than it was in Darwin's time, I essentially review the evolution of the theory of evolution, i.e., Darwinism, neo-Darwinism, molecular genetics, and the molecular genetics of evolutionary development, so-called *Evo Devo.* Part II, Intelligent Answers to Intelligent Design will respond to the objections of the Intelligent Design creationists and show why none of those objections are valid and that Intelligent Design does not prove that a supernatural being or force was necessary to explain the creation of life in all of its wonderful diversity and forms.

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Chapter 1

Evolution of the Theory of Evolution

The theory of evolution itself has evolved from the initial concept of Darwin to the modern concepts of evolution based on the subsequent exponential expansion in our knowledge of biology, molecular genetics and development. I will start with Darwin.

Darwinian Evolution

In 1859 Charles Darwin (1809–1882) published his classic treatise *The Origin of Species by Means of Natural Selection or the Preservation of Favored Races in the Struggle for Life.* [1] Ernst Mayr [2] termed his theory of evolution,

> …the greatest of all scientific revolutions. It represented not merely the replacement of one scientific theory ('immutable species') by a new one, but it demanded a complete rethinking of man's concept of the world and himself: more specifically, it demanded the rejection of some of the most-widely held and most-cherished beliefs of western man. In contrast to the revolutions in the physical sciences (Copernicus, Newton, Einstein, Heisenberg), the Darwinian revolution raised profound questions concerning man's ethics and deepest beliefs.

To give the reader a flavor of his book, I will frequently quote directly from Darwin, thus letting him explain his theory in his own words. In his introduction he stated:

> I can entertain no doubt, after the most deliberate study and dispassionate judgment of which I am capable, that the view which most naturalists until recently entertained, and which I formerly entertained—namely that each species has been independently created—is erroneous. I am fully convinced that species are not immutable; but that those belonging to what are called the same genera are lineal descendents of some other and generally extinct species in the same manner as the acknowledged varieties of any one species are descendents of that species. Furthermore, I am convinced that Natural Selection has been the most important, but not the exclusive, means of modification.

Ironically, although Darwin is known for his "theory of evolution," he only used that word once and that was the last word in the book.

> There is grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed laws of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been and are being evolved.

The essence of Darwin's theory was that species evolved through a series of minor inherited variations and that by natural selection the variations that were the most favorable were retained. Over many generations this led to new species.

The last sentence in his book indicates the thought that "the Creator" placed on earth a few or only one initial creature and all others evolved from that. In his section on Recapitulation and Conclusions he stated,

> I see no good reason why the views given in this volume should shock the religious feelings of anyone….A celebrated author and divine [clergyman] has written to me that 'he has gradually learnt to see that it is just as noble a conception of the Deity to believe that He created a few original forms capable of self-development into other and needful forms, as to believe that He required a fresh act of creation to supply the voids caused by the action of His laws.

Despite these caveats, all 1,200 original copies of the *The Origin of Species* sold out the same day it was released, and caused a storm of religious controversy.

Some of the data leading to Darwin's novel theory was collected when he was a naturalist on the H.M.S. Beagle that sailed the Pacific between 1831 and 1839. However, many years passed before the *The Origin of Species* was published. Darwin himself stated that an epiphany occurred when he read the book by Malthus called *Population* concerning the potential problems of human overpopulation. In his introduction, Darwin said,

> This doctrine of Malthus applies to the whole animal and vegetable kingdoms. As many more individuals of each species are born than can possibly survive; and as, consequently, there is a frequently occurring struggle for existence, it follows that any being, if it vary however slightly in any manner profitable to itself, under the complex and sometimes varying conditions of life, will have a better chance of surviving, and thus be naturally selected. From the strong principle of inheritance, any selected variety will tend to propagate its new and modified form.

One of the few diagrams in Darwin's book (Figure 1) illustrates his concept of the origin of new species.

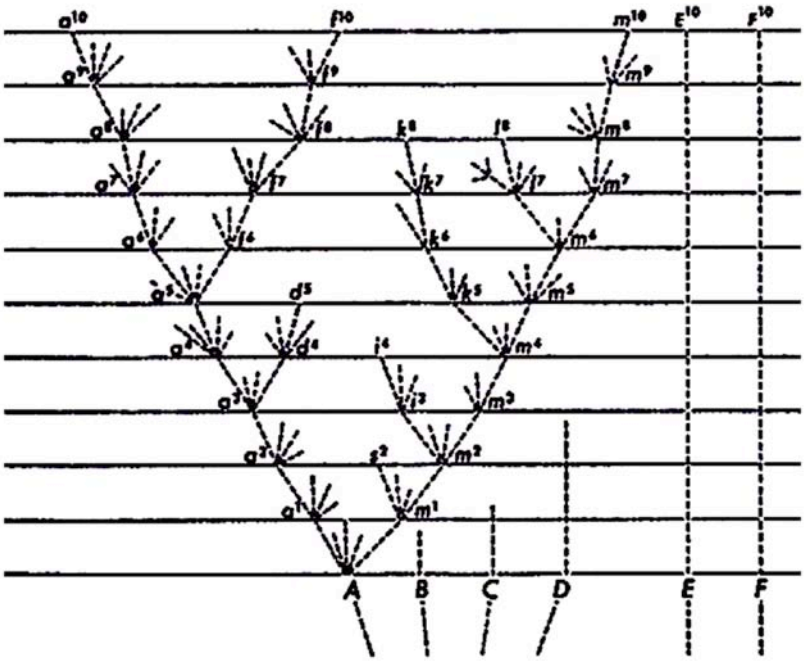

Figure 1. Diagram from Darwin's The Origin of Species. *See text.*

In referring to this figure Darwin said,

> As all the modified descendents from a common and widely-diffused species will tend to partake of the same advantages which made the parent successful in life, they will generally go on multiplying in number as well as diverging in character: this is represented in the diagram by the several divergent branches from (A). The modified offspring from the later and more-highly improved branches in the lines of descent will often take the place of, and so destroy, the earlier and less improved branches: this is represented in the diagram by some of the lower branches not reaching the upper horizontal lines. In some cases no doubt the process of modification will be confined to a single line of descent and the number of modified descendents will not be increased.
>
> After ten thousand generations, species (A) is supposed to have produced three forms, a^{10}, f^{10} and m^{10}, which having diverged in character during the successive generation, will have come to differ largely, but perhaps unequally, from each other and from their parent.

In this diagram Darwin laid out all of the important elements of his theory of evolution with minor changes slowly accumulating over thousands of generations to produce multiple branches and new species and old extinctions based on natural selection. Darwin even allowed for some species to progress through thousands of generations unchanged (E, F), but felt that this was fairly rare. This foreshadows the more-recent proposal of evolution by punctuated equilibrium, whereby rapid evolutionary change may be followed by long periods of no change.

Self-Criticism

Darwin was his own severest critic. He raised many of the concerns voiced by the Intelligent Design movement long before they did. His chapter VI was entitled, *Difficulties of the Theory.* He states:

> Long before the reader has arrived at this part of my work, a crowd of difficulties will have occurred to him. Some of them are so serious that to this day I can hardly reflect on them; but, to the best of my judgment, the greater number are only apparent, and those that are real are not, I think, fatal to the theory.

The following were some of his concerns:

1. Absence of intermediates. Darwin often viewed the fossil record as more of an embarrassment than as an aid to this theory.[3] Darwinian theory predicts the presence of many intermediate forms, if not in the present time, then at least in the fossil record. There was, however, an embarrassing dearth of such intermediate forms. He states:

> By this theory innumerable transitional forms must have existed; why do we not find them embedded in countless numbers in the crust of the earth?

His primary answer to this was that the fossil record was incomplete. The intermediate forms existed but they had not yet been discovered. There is some degree of truth to this. Paleontology has come a long way since Darwin's time, and in many cases, intermediate forms have been found, but in many cases they have not.

He also suggested that the intermediate forms existed for only a short period of time or in a very limited geographical area, thus greatly contributing to the difficulty of finding them in the vast excess of more developed forms. An additional reason he alluded to but did not explicitly state is that some forms, such as E and F in the figure, may have continued through thousands of generations essentially unchanged. Here the intermediate parental forms would be difficult to find in the vastness of unaltered forms.

2. Organs of extreme perfection and complication. In addition to few intermediate forms, the issue of complex structures is one of the most common objections to

Darwinian theory voiced by the Intelligent Design group. Darwin thought of it first. He stated,

> To suppose that the eye with all of its inimitable contrivances for adjusting the focus to different distances, for admitting different amounts of light, and for the correction of spherical and chromatic aberration, could have been formed by natural selection, seems, I freely confess, absurd in the highest degree.

He then stated he could find no other cases where the origin of a complex organ could not be explained by numerous, successive minor modifications. Other aspects of this subject so important to the Intelligent Design movement will be discussed later.

3. Organs of little apparent importance. A third area that Darwin found potentially troubling related to structures that seemed so unimportant that it was difficult to see how they could be formed by natural selection. His answer to this was that "organs now of trifling importance have probably been of high importance to an early progenitor."

4. The sudden appearance of groups of species. Darwin stated,

> The abrupt manner in which whole groups of species suddenly appear in certain formations, has been argued by several paleontologists as a fatal objection to the belief in the transmutations of species.
>
> I allude to the manner in which species belonging to several of the main divisions of the animal kingdom suddenly appear in the lowest known fossiliferous rocks.

It was known then that many new large groupings or phyla of animals seemed to have suddenly appeared in the Cambrian period. This was known as the Cambrian explosion. This interesting event is discussed in detail later. Darwin assumed there must have been a long period of animal evolution prior to the Cambrian explosion.

> Before the lowest Cambrian striatum was deposited, long periods elapsed, as long as, or probably longer than, the whole interval from the Cambrian age to the present day; and that during these vast periods the world swarmed with living creatures.
>
> To the question why we do not find rich fossliferous deposits belonging to these assumed earliest periods prior to the Cambrian system, I can give no satisfactory answer.

Again he blamed an incomplete fossil record and even suggested the missing fossils might be under the vastness of the Pacific Ocean. As we shall see later, his assumption of an incomplete fossil record does explain part of the story. The

precursor life forms did not have the calcified exterior skeletons required to leave a good fossil record. Since Darwin's time some of the more subtle non-calcified records of life forms prior to the Cambrian period have been found. In addition, the field of molecular evolution, or the examination of the relationships between species based on the amino acid sequence of proteins and the nucleic acid sequence of DNA, has powerfully supported evolution but it was not even dreamed of in Darwin's time.

*5. Difference between Species and Varieties.*The first chapter of Darwin's *The Origin of Species* is entitled *Variation under Domestication.* We are all familiar with the wide variety in size, appearance, color, and other characteristics of different breeds of dogs and other domesticated species. Despite these differences, interbreeding produces fertile offspring. By contrast, interbreeding between species usually results in infertile or no offspring.

This puzzled Darwin, who stated,

> How can we account for species, when crossed, being sterile or producing sterile offspring, whereas, when varieties are crossed their fertility is unimpaired?

Each of these issues that bothered Darwin has been incorporated into the objections of the Intelligent Design group as evidence for the failure of Darwin's Theory of Evolution. Darwin thought of them first and, of course, did not view them as evidence against his theory. As outlined above he had an explanation for many of the anomalies. The solution of others would require waiting for further advances in biological knowledge.

Darwin was his own severest critic. He recognized that his theory was a work in progress and that some issues were troublesome, even to him. These included:

- **the frequent absence of intermediate forms**
- **the existence of structures of great complexity**
- **the presence of organs of little importance**
- **the sudden appearance of large groups of species**
- **the difficulty in defining a species versus a variety.**

These issues largely had to await the work of others to be fully resolved.

Genetics and Neo-Darwinism

One of the major problems that Darwin faced was that the basic tenets of genetics had not yet been formulated. Thus, when he proposed that evolution was a result of the selection for advantageous inherited variations, the mechanism by which this could happen was a total mystery and would remain a mystery until 1900, 41 years after the publication of *The Origin of Species*.

Shortly after Darwin's work was published, Gregor Mendel, a monk in an Austrian monastery, was actually carrying out the experiments that led to an understanding of the basic concepts of genetic inheritance. He carefully recorded the results of crossing different varieties of peas. These results, published in a short monograph entitled *Experiments with Plant Hybrids,* showed that traits or mutations were inherited and transmitted as intact elements or units in successive generations. This work remained unappreciated until 1900, when three different scientists independently and almost simultaneously re-discovered Mendel's work.

This supplied an important missing link. In the first several decades of the twentieth century, remarkable advances were made in understanding the nature of these units called genes, the nature of dominant and recessive mutations, and how new mutations spread in populations. For example, H. Norton, a British mathematician, found that even *a small selective advantage of less than 10 percent led to drastic genetic changes in just a few generations.*

The combination of a rapidly increasing knowledge of genes and genetics, genes in populations (population genetics), and many related sciences led to the formulation of a new synthesis known as *neo-Darwinism.* Some of the most important publications for this new synthesis were Dobzhansky's 1937 book, *Genetics and the Origin of Species* [4] and Julian Huxley's 1940 books, *The New Systematics* [5] and *Evolution, The Modern Synthesis.* [6]

At a 1946 international symposium at Princeton, New Jersey, attended by all of the major workers in the field, there was unanimous endorsement of the gradualness of evolution, the importance of natural selection, the role of genes in populations, the role adaptation and diversification, the falsity of the inheritance of acquired characteristics, and the definition of a species as organisms that in nature mate to produce fertile offspring. [2]

This agreement was termed the *Modern Synthesis.* It was modern in that the new field of Mendelian genetics was now added. It was a synthesis in that it provided an agreement between two previously opposing groups. On the one hand there were the paleontologists who only saw the development of new species over long periods of geological time and referred to the process as macroevolution—the apparent sudden development of new species. On the other hand there were the population geneticists who saw evolution as a gradual change in the frequencies of variant genes due to selection or change in gene frequencies simply due to random genetic drift.

Remarkably they came to the agreement that the macroevolution of the paleontologists was the outcome of the continued and accumulative slow changes or the microevolution within a species observed by the population geneticists. Macroevolution in the sense of the sudden appearance of a new species, the "hopeful monsters" or "divine creation," did not exist. There was essentially no difference between microevolution and macroevolution. The difference was only a matter of degree. Of particular importance, studies of the mechanism of microevolution were relevant to macroevolution or speciation.

Molecular Genetics

The powerful addition of genetics to the theory of evolution occurred before Watson and Crick figured out the structure of DNA, thus setting off the revolutionary era of molecular genetics and molecular evolution.

In a one-page article published in *Nature* in 1953 James Watson and Francis Crick reported their work on deciphering the structure of deoxyribose nucleic acid or DNA.[7] In their opening paragraph they modestly state:

> "We wish to suggest a structure for the salt of dexoyribose nucleic acid (D.N.A.). The structure has novel features which are of considerable biological interest."

Their diagrammatic representation of DNA was as follows:

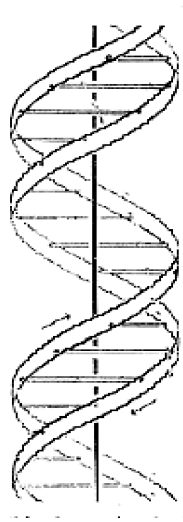

Figure 2. Diagram of the structure of DNA. From Watson and Crick.[7]

The legend for this figure read:

> The figure is purely diagrammatic. The two ribbons symbolize the two phosphate-sugar chains, and the horizontal rods the pairs of bases holding the chains together. The ventral line marks the fibre axis.

The phosphate-sugar and bases are arranged as follows:

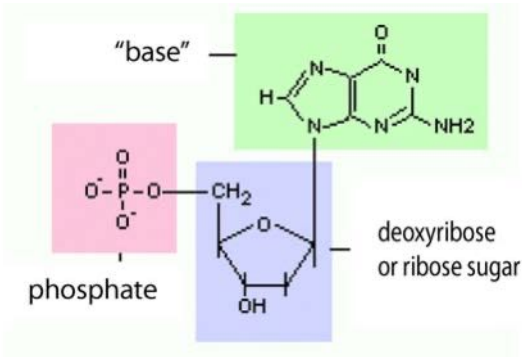

Figure 3. A deoxyribose nucleic acid

The key to the structure was the pairing by hydrogen bonds of the nucleic acids adenine (A) with thymine (T) and guanine (G) with cytosine (C) as follows:

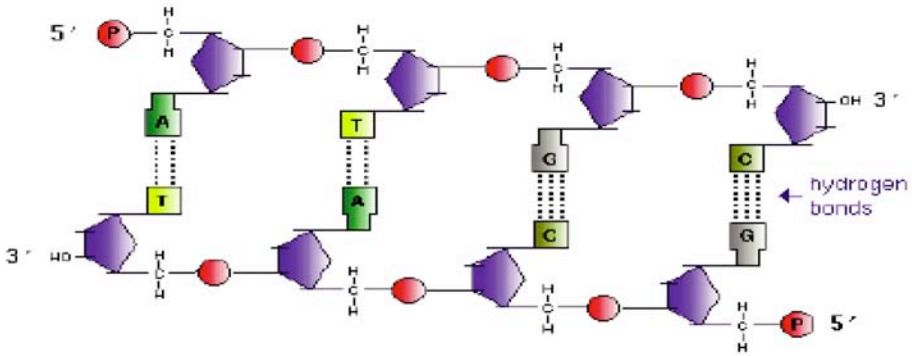

Figure 4. Base pairing of A:T, T:A, G:C and C:G. [8]

In this figure the sequence of base pairs is A-T, T-A, G-C, and C-G. If the top strand (5' to 3' strand) is read, the base sequence would be ATGC. If the bottom strand (3' to 5') is read, the complement sequence is TACG. The sequence of these base pairs is the key to understanding the entire field of genetics. In the sections of DNA that form the genes, this sequence is read into a second form of nucleic acid termed ribose nucleic acid or RNA, specifically messenger RNA. Based on the genetic code, where three bases code for each of the 20 amino acids, the messenger RNA is translated into specific proteins such as the globin of hemoglobin, or enzymes such as cytochrome oxidase.

Watson and Crick ended their article with the famous understatement:

> It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material.

By this they referred to the fact that when the two phosphate-sugar chains separated, the specific A-T and G-C pairing allowed two new identical copies of DNA to be formed. This finally solved the problem of how one cell can divide to form two identical daughter cells with all the genetic information intact.

Over the next 15 years the genetic code was deciphered. The results are shown in Figure 5. This table shows the three-letter code for each of the amino acids. The letters in the left column show the first base, the letters on the top row show the second base, and letters for the third base are shown in each of the three letter codes. Thus, a sequence of CTT would code for the animo acid leucine *(leu or L)*. It can be seen that some amino acids such as leucine are produced by six different codes; some such as proline *(Pro or P)* are produced by four different codes, some such as cysteine *(Cys or C)* are produced by two codes, and some such as tryptophan *(Try or W)* are produced by only one code. *Ter* stands for termination. When this code is present, the synthesis of the protein stops.

	T	C	A	G
T	TTT Phe (F) TTC " TTA Leu (L) TTG "	TCT Ser (S) TCC " TCA " TCG "	TAT Tyr (Y) TAC TAA **Ter** TAG **Ter**	TGT Cys (C) TGC TGA **Ter** TGG Trp (W)
C	CTT Leu (L) CTC " CTA " CTG "	CCT Pro (P) CCC " CCA " CCG "	CAT His (H) CAC " CAA Gln (Q) CAG "	CGT Arg (R) CGC " CGA " CGG "
A	ATT Ile (I) ATC " ATA " **ATG** Met (M)	ACT Thr (T) ACC " ACA " ACG "	AAT Asn (N) AAC " AAA Lys (K) AAG "	AGT Ser (S) AGC " AGA Arg (R) AGG "
G	GTT Val (V) GTC " GTA " GTG "	GCT Ala (A) GCC " GCA " GCG "	GAT Asp (D) GAC " GAA Glu (E) GAG "	GGT Gly (G) GGC " GGA " GGG "

Figure 5. The genetic code.

When the sequence of amino acids in proteins in widely different species was determined it was found that they were similar. Since the differences were greater when the evolutionary distance between two species was greater, the study of protein sequences served as both a biological clock and a means of examining the branching in the tree of life such as that drawn by Darwin. As sequencing techniques improved, the sequence of bases in RNA and DNA were also determined. RNA differs from DNA in that uracil is used in the place of thymine, ribose is used in the place of deoxyribose, and RNA is usually single-stranded. The structural difference between deoxyribose and ribose is as follows:

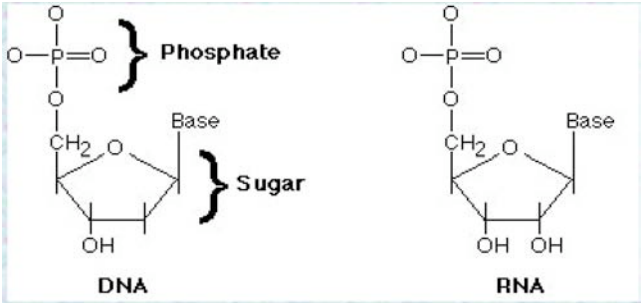

Figure 6. Deoxyribose versus ribose.

The difference is that ribose has two -OH groups while the deoxyribose of DNA has only one. The pathway by which genes in chromosomes code for proteins is diagrammed in Figure 7.

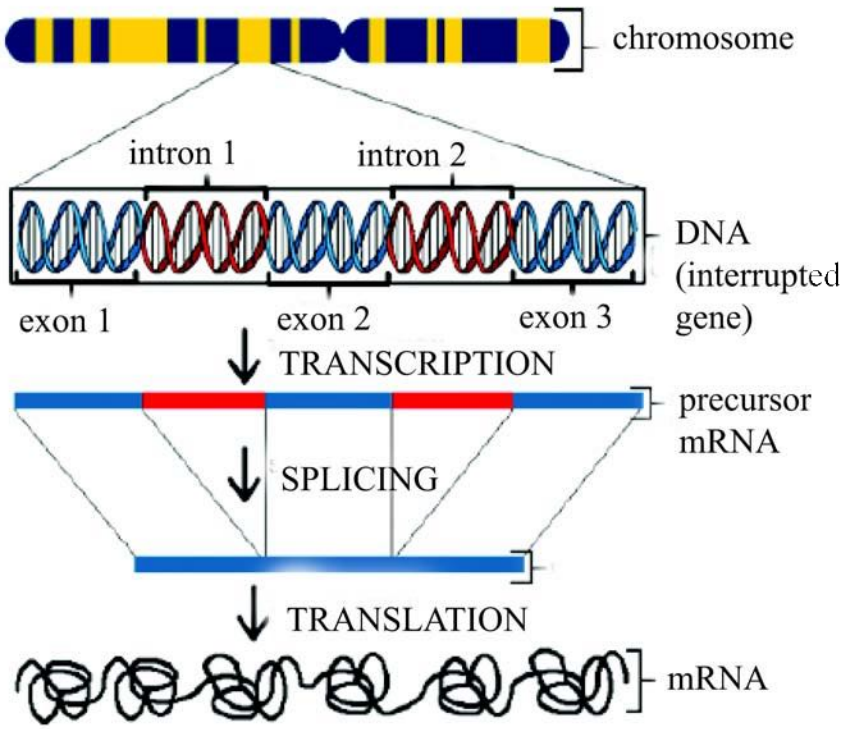

Figure 7. The chromosomes (top) contain a linear string of thousands of genes, one of which is shown. Genes are divided into exons whose sequence is utilized to determine the sequence of amino acids in proteins, and regions between the exons are called introns. The sequence of both the introns and the exons are translated into pre-messenger RNA, but the RNA corresponding to the introns is spliced out. This produces messenger RNA (mRNA) which directs the sequence of amino acids in the proteins. Most of the proteins are enzymes that catalyze specific chemical reactions in the body. [8]

From an evolutionary aspect, the important point is that organisms from bacteria to man possess many similar genes and proteins and the sequences of these genes and proteins show them to be genetically related. Half of the genes present in yeast are also present in humans. Actin is an important structural component of the cytoplasm of eukaryotes, analogous to the internal wooden framework of a house. The sequence of the actins of yeast and the actins of humans are 91 percent similar in their sequence. More than 99 percent of the genes of mice have homology to human genes.[9] As illustrated in subsequent parts of this book, the study of amino acid, RNA, and DNA sequences has provided an extraordinarily powerful verification of the inter-relatedness of the species and of their evolution from common ancestors.

Organisms from bacteria and yeast to mice and man possess many similar genes, and the sequences of these genes show them to be genetically related. This provides an extraordinarily powerful verification of the inter-relatedness of the species and of the evolution of modern species from common ancestors.

Evolutionary Developmental Genetics

The final important development has been the marriage of molecular genetics with development termed *evolutionary developmental biology* and dubbed "Evo Devo." The most remarkable aspect of this part of the story is the identification of a constant set of genes involved in determining all the different body plans. This has been called the developmental "toolbox." These developments were described by Sean Carroll in *Endless Forms Most Beautiful: The New Science of Evo Devo.*[10]

Much of what we have learned has been so stunning and unexpected that it has profoundly reshaped our picture of how evolution works. Not a single biologist, for example, ever anticipated that the same genes that control the making of an insect's body and organs also control the making of our bodies.

With these developments Darwin's original theory of evolution now had three powerful companions—genetics, molecular genetics, and molecular developmental genetics. In the following sections we will see how these help to provide effective responses to those who seek to attack the theory of evolution. I will first provide some general background information about the evolution of the earth and the Tree of Life.

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Chapter 2

The Tree of Life

The purpose of this section is not to give a course in geology and paleontology but to introduce to the readers who may not be familiar with this material a brief, non-technical outline of some of the highlights of these fields of science. The unfolding of progressively more complex life forms over the long periods of geologic time has often been referred to as the Tree of Life. Geologic time is divided into progressively smaller units of time progressing from eons, eras, and periods to epochs. The time is given in *Ma,* or millions of years ago. These are summarized in Figure 2. The levels of atmospheric oxygen (O_2) are shown in blue on the left. The eons are very large blocks of time starting with the Hadeon, lasting one billion years from the birth of the earth 4.6 billion years ago to the very beginnings of primitive life. [1]

The **Archean** (ancient life) also lasted approximately a billion years and was the age of bacteria, especially the blue-green cyanobacteria (Figure 1).

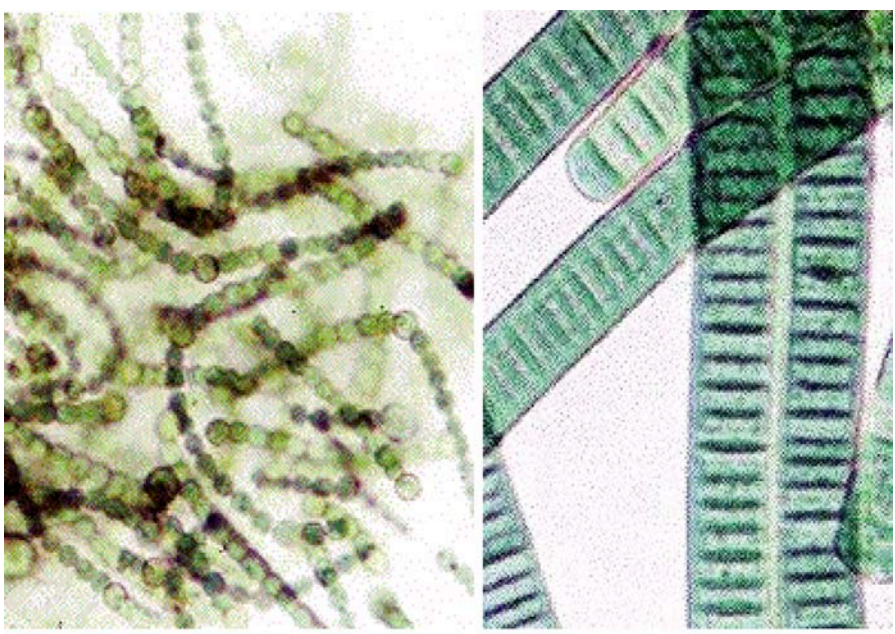


Figure 1. Blue-green Cyanobacteria [2]

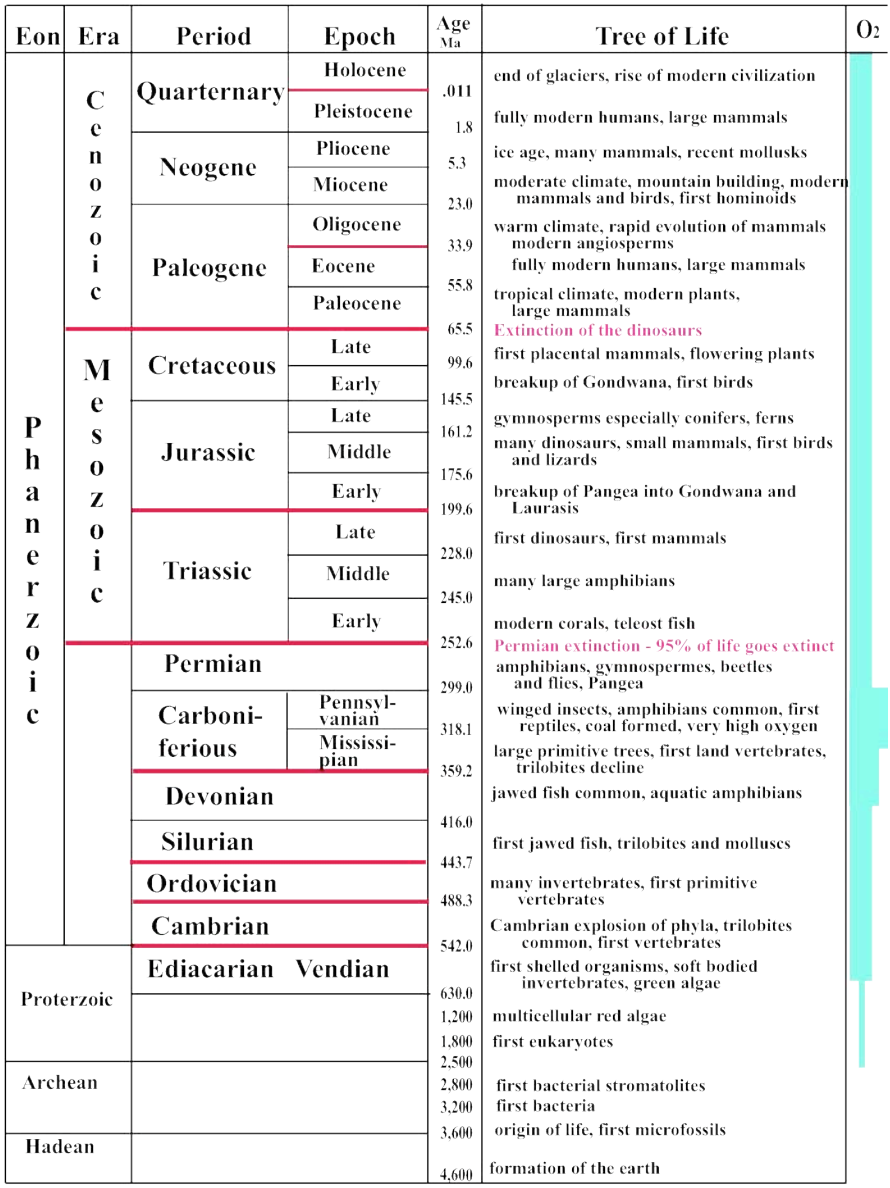
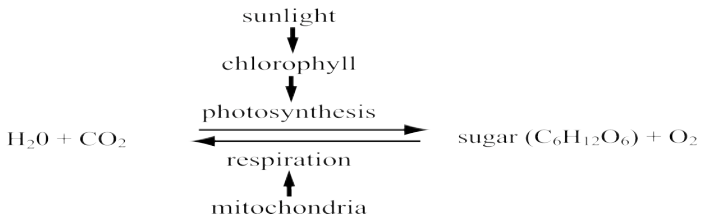


Figure 2. See text

The cyanobacteria evolved early and subsequently changed little through to modern times. They were uniquely suited for life on a young planet where the atmosphere contained hydrogen, nitrogen, methane, carbon dioxide (CO_2) and little or no oxygen (O_2)—totally unsuitable for modern animals. Their blue-green color is due to the presence of chlorophyll. This allows for photosynthesis, the process of

using the energy of sunlight to convert water (H_2O) and CO_2 to sugar and oxygen. Other bacteria perform respiration and reverse the process converting sugar and O_2 to water and CO_2. This is diagrammed as follows:



This process provided a major source of the oxygen that eventually accumulated in the atmosphere around 2.2 billion years ago. Cyanobacteria have been described as the most important organism to ever inhabit the earth. [3] This may come as a blow to those who think man is the most important organism. However the cyanobacteria have been present on earth for 3.6 billion years compared to man's one million years, 3,600 times longer. Bacteria have no nucleus and are thus termed prokaryotes (pro = before karyo = nucleus). This long period of time allowed prokaryotes to percolate for over 2.5 billion years before evolving to eukaryotes (eu = true) with a nucleus.

The other great contribution of the cyanobacteria is that they played a crucial role in the origin of plants. They possessed chlorophyll and thus in the presence of sunlight they had had the biochemical machinery to convert carbon dioxide and water into sugar and oxygen. Organisims that were precursors to plants ingested cyanobacteria and were able to convert the energy from the sun to oxygen.

The **Proterzoic** (before abundant life) ranged from 543 million to 2.5 billion years ago. During this period the bacteria continued to flourish, but a novel new group of organisms called archaeans appeared. The Proterzoic was also the period during which the cyanobacteria produced a build-up of oxygen in the atmosphere. This build up led to the extinction of many bacterial groups but also made possible the explosive evolution of the eukaryotes beginning 1.8 billion years ago. The oxygen levels increased to almost 30 percent during the Carboniferous and Permian periods, then dropped at the end of the Permian extinction. [4]

The **Vendian** is a period of time from 543 to 600 million years ago, in the late Proterzoic, during which the first multi-cellular organisms appeared. As noted above, Darwin was concerned about the apparent absence of life forms prior to the Cambrian explosion. He thought there was a long period of evolution of more primitive life forms prior to this but that the fossil record was still incomplete. He was correct. Since these earlier forms were soft-bodied they did not have calcified skeletons and thus were harder to find. The fossils of the Vendian period are important because they represent the first multicellular organisms. Figure 4 shows some of these fossils.

Figure 4. Vendian fossils.[5] Left. *Dickinsonia possibly related to annelid worms or cnidarian polyps (jellyfish, corals, other stinging forms).* Middle. *Spriggia were initially thought to be an annelid (segmented worm) but later thought to be related to arthropods with external skeletons made of chitin.* Right. *Tribrachidium heraldicum, an unusual dish-shaped form with three-part symmetry. Possibly related to corals and anemones or sea urchins and seastars.*

The **Ediacaran** period is concurrent with the Vendian and based on Ediacarian fossils found in Australia, Canada and China. Recent dating based on the decay of radioactive uranium to lead indicated this period was from 551 to 635 million years ago.[6] These fossils are similar to the other Vendian fossils. Since they have soft bodies that do not preserve well, the evidence for their existence often depended upon the trails they left in the mud.

Figure 5. Some pre-Cambrian fossils appear to be precursors of modern animals. Primitive worms made these simple burrow and trace fossils. These and other Ediacara forms survived the late Protozoic extinction and took part in the Cambrian explosion[7]

Most of the Vendian/Ediacaran organisms that populated the pre-Cambrian oceans became extinct as "failed experiments in evolution." Some, however, do appear to be precursors leading to the subsequent Cambrian explosion. Thus, as Darwin predicted,

> Before the lowest Cambrian striatum was deposited, long periods elapsed, as long as, or probably longer than, the whole interval from the Cambrian age to the present day; and that during these vast periods the world swarmed with living creatures.

He was absolutely correct.

Small shelly fauna. The first fauna with hard parts are called the *Tommotian* after a locality in Russia where they were first found. They were subsequently found worldwide. These have been termed *small shelly fauna.*

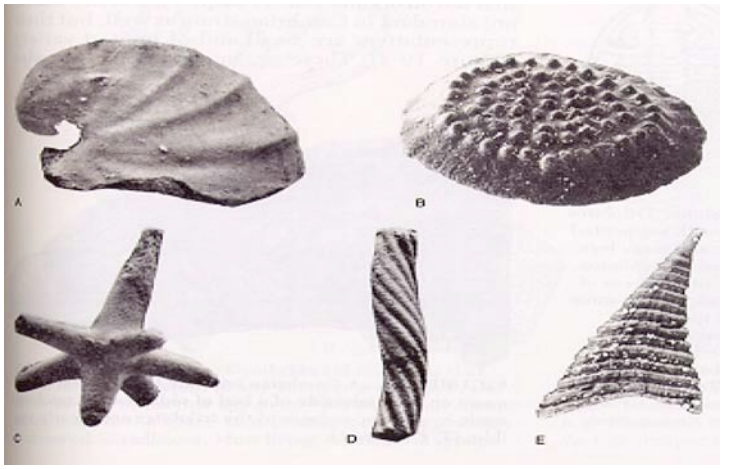


Figure 6. Small Shelly Fauna from the Tommotian Age From left to right, top to bottom: *Latouchella, a Helcionelloid mollusk; a Microdictyon-like form (the mineralized eye of a lobopod); Chancelloria—a spicule from a superficially sponge-like Procoelomate (Class Coeloscleritophora); a vermiform specimen and Tommotia, an angular shell from an animal of uncertain affinities, but presumably another Procoelomate—Class Tommotiida.* [8]

Like most of the Ediacara, the small shelly fauna were also a failed evolutionary experiment. The last great eon is the Phanerzoic (period of life). Its subdivisions are shown in Figure 2. The important points are the progressive increase in complexity of the different species and the periods of extinctions.

Extinctions. The red lines in Figure 2 represent periods of major and minor mass extinction of life forms. These extinctions were due to a range of factors including the impact of comets, dramatic shifts in temperature or in the composition of the atmosphere, and movements of the continents (plate tectonics). Mass extinctions of many species have played an important role in evolution. They clear out ecological niches and allow new species to fill in and evolve into the resulting empty spaces. Some of the most dramatic were the Great Permian Die-off at the end of the Permian period where more than 50 percent of families and more than 95 percent of species died off. The Cretaceous (K/T) mass extinction resulted in the extinction of all vertebrates that weighed more than 25 kg (55 pounds). Since these were the large dinosaurs, this is known as the dinosaur extinction. This extinction is believed to have been the result of a giant asteroid crashing into earth near the Yucatan Peninsula and producing a worldwide nuclear winter. The Pleistocene extinction resulted in the disappearance of large mammals and birds and coincided with the arrival of the first humans.

Many mass extinctions that occurred over geologic time periods cleared out old species from ecological spaces and played a major role in allowing the accelerated evolution of new species.

Tree of Life. One form of RNA is called *ribosomal RNA*. This is present in ribosomes, the structures that translate the specific sequence of nucleic acids in messenger RNA into a specific sequence of amino acids in proteins. This is a fundamental function that all organisms must perform in order to exist. The sequencing of ribosomal RNA by Dr. Carl Woese[9] provided the first evidence for the existence of a unique group of organisms, the archeans. These bacteria-like organisms lived at the high temperatures of volcanic hot springs and produced methane (CH_4). The sequence of their ribosomal RNA was distinctly different from that of either bacteria or eukaryotes. As a result of these studies Woese proposed three domains of life: eukaryotes, bacteria and archaea.

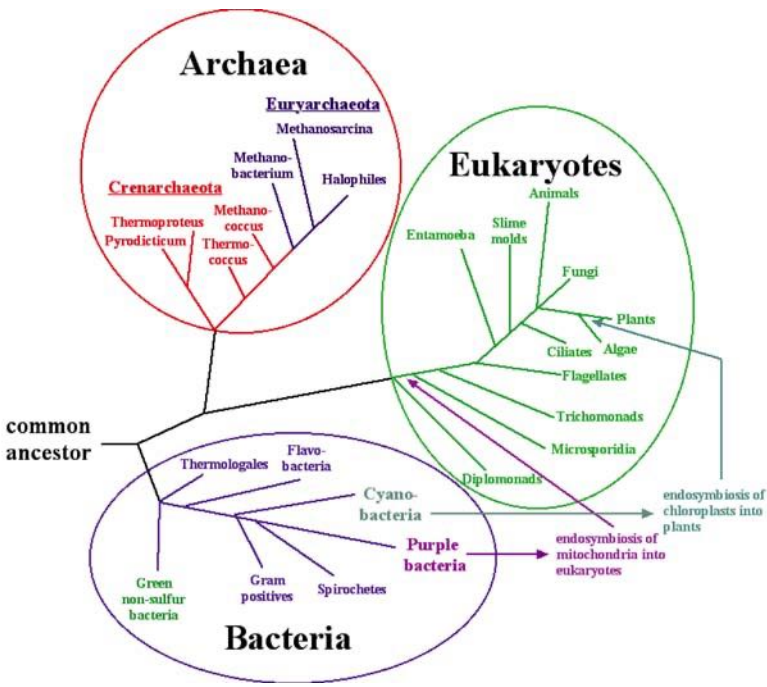


Figure 7. The three-kingdom system proposed by Carl Woese based on the sequence of ribosomal RNA. Most but not all of the sub-branches are shown. Modern eukaryotes contain mitochondria that were derived from purple bacteria by endosymbiosis (see purple arrows), and plants have chloroplasts derived from blue-green cyanobacteria by endosymbiosis (see blue-green arrows).

This diagram indicates that a very ancient ancestor was common to the three Kingdoms. The incorporation a whole organelles, such as chloroplasts, into a different organism is called endosymbiosis. This process was also responsible for the incorporation of mitochondria into the cells of eukaryotes. Mitochondria are membrane lined organelles with their own DNA. They are responsible for the respiration of oxygen. Figure 8 shows the membrane-rich mitochondria.

Figure 8. Electron micrograph of a mitochondria inside the cell. [10]

Plants are able to carry out photosynthesis because they contain chloroplasts with chlorophyll. Chloroplasts also have their own DNA and are also present as a result of endosymbiosis.

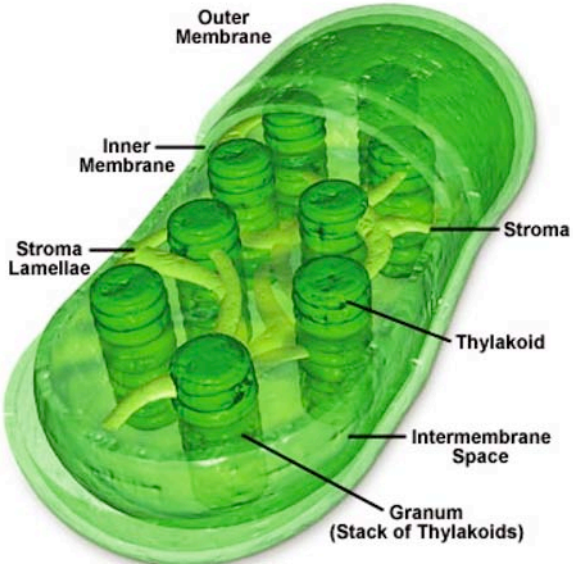


Figure 9. 3D reconstruction of a chloroplast. The thylakoids are the site of the initial conversion of sunlight energy into chemical energy ATP. [11]

Because these two organelles are surrounded by their own membranes and have their own DNA they are believed to have been free-living organisms at one time. They carried out vital functions related to the production of energy. Mitochondria were incorporated by endosymbiosis into purple bacteria, and chloroplasts were incorporated into cyanobacteria. These organelles contributed to the metabolism of these bacteria for several billion years. About 600 million years ago, further endosymbiosis provided eukaryotes with mitochondria and plants with chloroplasts.

Endosymbiosis indicates how innovative the process of evolution can be. Instead of repeatedly re-inventing structures, evolution simply incorporated "old parts" that functioned well in bacteria to make new, more-complex organisms.

Horizontal gene transfer. Evolution has carried the concept of "no need to re-invent the wheel" into two other areas—the horizontal transfer of whole genes and the re-use of parts of genes. While the tree shown in Figure 7 has a common ancestor, in reality the situation is not as clear-cut as it may seem. The complete sequencing of an archaea *Methanococcus janaschii* in 1996 showed that it shared only 11 to 17 percent of its genes with bacteria and that more than 50 percent of its genes were unknown to either bacteria or eukaryotes. This confirmed that archaea belonged to a distinct domain. While archaea were more closely related to eukaryotes than bacteria, assigning a clear root to this tree was difficult. All three domains shared the same genetic code indicative of a common origin. The bacteria and archaea carried their DNA in the form of a circle and had no nucleus. On the other hand, the archaea and eukaryotes share many features not seen in bacteria. Finally, the bacteria and eukaryotes have some characteristics of the chemical nature of their membranes not shared by archaea.

The solution to this confusion came when it was realized that horizontal gene transfer was taking place. This occurs when one organism takes up the DNA of another organism. The advantage of gene transfer is that if one species evolved a solution to a specific problem, another species could benefit by simply picking up the genes involved. This would accelerate the process of evolution. However, it would be a disadvantage if this process was too efficient since this would eventually retard evolution by widespread dissemination of "unique variations." How could an organism with an advantageous mutation maintain a selective advantage if its competitors quickly obtained the same mutation by horizontal gene transfer? The concept of patent protection had not yet been developed. The development of a nucleus around the DNA of multicellular organisms retarded horizontal gene transfer, resulting in a further acceleration of the pace of evolution.

The horizontal transfer of whole genes from one species to another was common early in evolution. While this could accelerate the adaptability of primitive organisms, the eventual restriction of this process was necessary for the evolution of more-complex organisms.

Transfer of parts of genes. A second change that occurred with the transition from prokaryotes to eukaryotes was a change in how genetic material was processed. The genes are separated into exons and introns. Exons code for different functions in a gene and this function (module) can be shared by different genes by a process called *exon transfer.* A reasonable analogy is a child's Tinkertoy® set. Tinkertoys® come with a range of different modules in the form of wheels, axels, struts, blades, motors, and

many other parts used to construct anything the child's imagination desires. A basic set of modules can produce many thousands of different toys. Endosymbiosis, gene transfer, and exon transfer use the same modular or Tinkertoy® approach. Thus, once a working system, organelle, gene, or gene part has evolved, it can be used over and over to generate new life forms. We will see later how this modularity provides a solution for two of the Intelligent Design group's major concerns—the evolution of complex systems and the assumption that evolution would take too much time.

In addition to having a nuclear membrane, eukaryotes also divided their genes into multiple exons and introns. Each exon coded for a specific modular function in the resulting protein. Like biological Tinkertoys®, rearranging, shuffling and exchanging exons allowed for the rapid evolution of new genes and again prevented the need to re-invent a module.

Preparation for the Cambrian explosion. A number of unique new aspects of the earth's atmosphere and the tree of life occurred in the late Proterozoic Era. These were:

- the accumulation of significant amounts of oxygen in the atmosphere
- partitioning DNA into chromosomes
- enclosing DNA in a membrane to form the nucleus and eukaryotes
- splitting the genes into exons and introns
- incorporation of mitochondria into eukaryotes
- evolution of the "developmental toolbox" (see Chapter 4)
- formation of multicellular organisms

The combination of all these novel features provided the major force for the sudden explosion of new life forms in the Cambrian Period.

For the first 2.5 billion years of life only single-cell bacteria existed. For the next 700 million years, single celled eukaryotes came on the scene. Immediately prior to the Cambrian Period there were two, largely failed evolutionary experiments, the Vendian/Ediacara fauna and the small shelly fauna. Following an accumulation of oxygen in the atmosphere and the development of multicellular organisms there came an explosion of new life forms—The Cambrian explosion.

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11. Figure from www.daviddarling.info/images/chloroplast.jp. By permission.

Chapter 3

The Cambrian Explosion

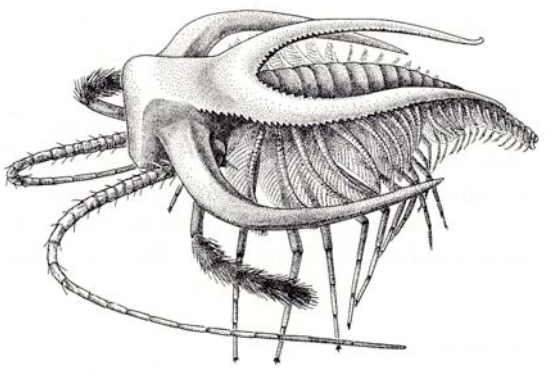
After all the necessary pieces were in place the stage was set for the age of the bacteria to come to an end and for multicellular eukaryotes to begin a rapid ascendancy. The most famous of the fossil deposits from the Cambrian Era were in the Burgess Shale in Yoho National Park in the Canadian Rockies. The sudden appearance of many different life forms was so dramatic that this is often referred to as the Cambrian explosion. The astounding aspect of the Cambrian explosion is that most of the modern animal phyla came into existence in this relatively short period of about 20 million years and no new animal phyla developed after that. Approximately 90 percent of the Burgess phyla became extinct.

The astounding aspect of the Cambrian explosion is that most of the modern animal phyla came into existence in this relatively short period of time and no new phyla developed after that.

This fossil bed was discovered by Charles Doolittle Walcott, who was both the director of the Smithsonian Institution and a paleontologist who worked in the field as well as sitting behind a desk. Walcott first discovered the Burgess Shale in 1909 late in the summer. Snowfall precluded extensive collecting but he recognized the value of his find and returned for a month each summer collecting fossils from 1910 through 1913. At the age of 67, he returned again in 1917. In all he brought back 80,000 specimens for storage in the Smithsonian Institution in Washington D.C. From 1911 to 1920 he wrote a series of reports on the Burgess fauna.

In his book *Wonderful Life,* Stephen Jay Gould [1] outlines in fascinating detail how Walcott "shoe-horned" all of the fauna of the Burgess Shale into a series of modern phyla. This fit perfectly with the classic Darwinian theory of slow progressive evolution from simpler to more complex forms of life, over time. These fossils then remained in storage for 50 years. Beginning in the 1970s three paleontologists—Harry Whittington and his two graduate students Simon Conway Morris and Derek Briggs, launched their own expedition. Instead of going to Canada they went to the dusty drawers in the back reaches of the Smithsonian Institution. They began a detailed re-examination of the Burgess Shale fossils and in the process launched a paradigm-changing re-assessment of the entire process of how evolution really works. A remarkable feature of the Burgess Shale fossils is that both hard and soft parts were preserved.

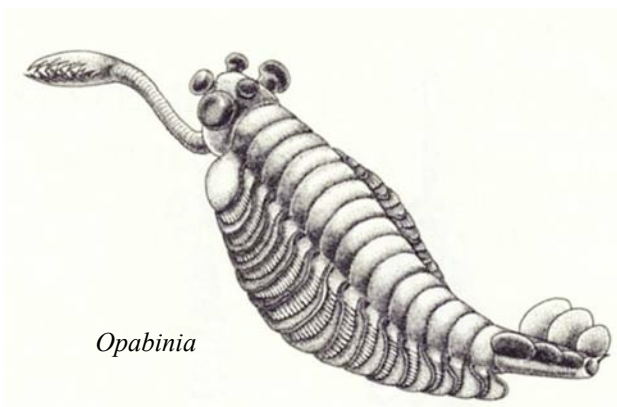
I would like to take the reader through a tour of this ancient Burgess Shale zoo to show the amazing diversity of this sudden explosion of multiple body forms, because the figures, taken from Gould's book, are a testament to the powerful creativity of evolution, and because the reconstructions by the artist Marianne Collins are things of beauty.



Marrella

The first organism to fall out of the Walcott shoehorn of modern phyla was *Marrella.* This remarkable creature possessed features that violated the key characters of every group of arthropods. Whittington struggled with how to classify it. He initially placed it in a group of trilobite-like organisms but quickly realized this was wrong. In reality it seemed to belong nowhere. Another organism called *Yohoia* with a large pair of grasping appendages also did not fit anywhere.

Whittington next examined *Opabinia,* an organism with a unique body plan consisting of five eyes in the head, a terminal claw, body sections with gills on the top and a tail piece in three segments. Two pairs of the eyes were on short stalks, a fifth was in the mid-line. While this unique phylum also went extinct, it is intriguing to imagine what we might look like running around with five eyes if this organism had been at the bottom of the tree leading to humans. Whittington initially thought *Opabinia* was an arthropod, meaning "jointed foot." However, a careful dissection showed no such appendages. As unique as they were, with no modern counterparts, *Marrella* and *Yohoia* were at least arthropods. By contrast, Opabinia did not fit into any known phyla. Gould [1p136] stated:

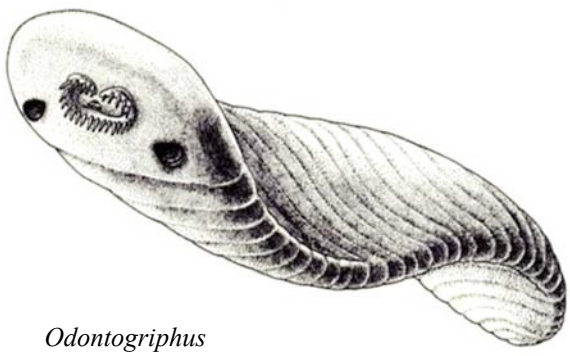


Opabinia

> I believe that Whittington's reconstruction of Opabinia in 1975 will stand as one of the great documents in the history of human knowledge. How many other empirical studies have led directly on to a fundamentally revised view about the history of life? We are awestruck by *Tyrannosarus;*

> we marvel at the feathers of *Archaeopteryx;* we revel in every scrap of fossil human bone from Africa. But none of these has taught us anywhere near so much about the nature of evolution as a little two-inch Cambrian odd-ball invertebrate named *Opabinia*.

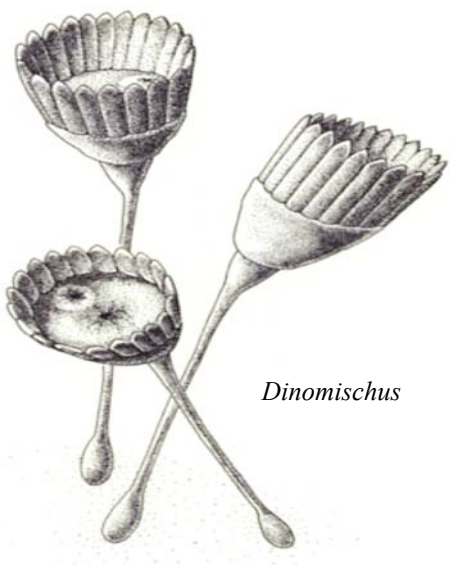
While Whittington's approach to the treasure trove of Burgess fossils in the Smithsonian Institution was to first examine the most common organisms, Simon Conway Morris's approach was the opposite. He searched the many drawers for the rare oddball fossils. *Nectocaris* is the first oddball organism he described. This looked mostly like an arthropod in front and a chordate with a tail fin behind. It did not fit into any known phylum.



Odontogriphus

Odontogriphus was the second oddball organism described by Conway Morris. Its mouth was surrounded by tentacles and the pair of palps (probable sensory organs) are shown on the underside of the head.

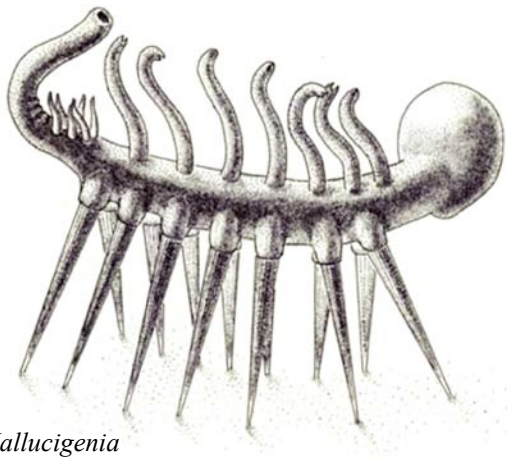
There were no appendages or indication of hardened areas, suggesting it was gelatinous. This further suggested the "Cambrian explosion" could simply be due to the absence of hard parts on the organisms allowing them to be visible as fossils. *Odontogriphus* also does not fit easily into any modern phyla.



Dinomischus

Dinomischus was the third mystery animal described by Conway Morris. It represented another major functional design consisting of a creature with a radial symmetry, suited to receiving food from all directions. Both the mouth and the anus were located close together on the upper stalk. Be thankful this also did not become the model for us. This was also a "bizarre thing unto itself" and "has no obvious affinity with other metazoans and presumably belongs to an extinct phylum." [2]

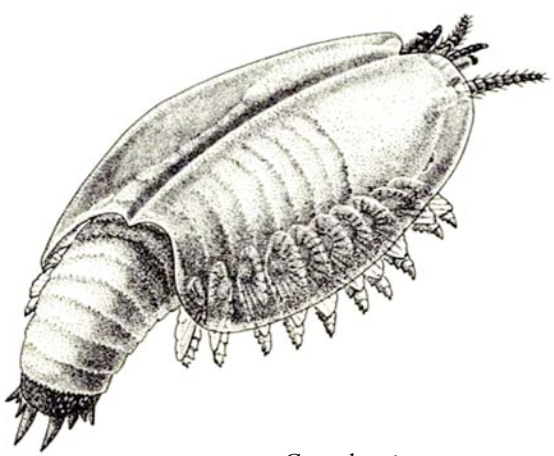
A fourth organism described by Conway Morris was *Amiskwia*, a flattened, gelatinous, swimming animal with a pair of tentacles on the head, and side and tail fins. This creature also did not fit well with any known phylum.



Hallucigenia

Hallucigenia, the fifth on Conway Morris's list, is the most stunningly bizarre of the lot. It is supported by seven pairs of unjointed struts allowing it to stand on the sea floor. There are seven tentacles with two pronged tips that extend upward from the large bulbous "head" to the opposite end "tail" Each tentacle may have been able to gather food and pass it to the communal gut. This organism was so difficult to classify that one consideration was that it was part of a larger, yet undiscovered creature, that would probably be even more bizarre. Some have suggested this figure is upside down with the tentacles on the bottom and the spikes on the top for protection. [3]

The third paleontologist of the trio, Derck Briggs, described a number of Burgess organisms, of which the first was *Branchiocaris,* considered by Walcott to be a Crustacea, which had five pairs of appendages in a specific arrangement. Careful examination showed it was not a Crusteacian and defied classification into any current group of arthropods.



Canadaspis

Canadaspis, the second organism that Briggs studied, was also the second most common animal in the Burgess Shale. This was a true Crusteacea. This abundance was probably a sign of its potential for success. This is the first of all the Burgess animals described so far to be placed in a successful modern group of organisms.

Whittington examined a second Burgess Shale animal to survive past the mid-Cambrian era called *Naraoia.* This animal represented a twig on the branch of

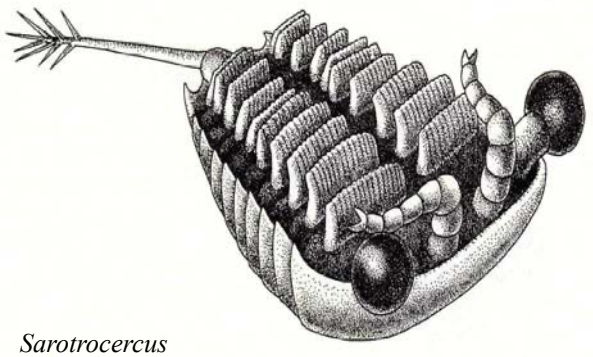
organisms that produced the trilobites. Trilobites survived to the end of the Paleozoic Era. A second Burgess Shale organism, *Tegopelte,* was also a trilobite.

Odaraia, a bivalved arthropod, had the largest eyes of any Burgess organism. The trunk contained forty-five limb-bearing segments, and a unique three-pronged tail more similar to that of sharks and whales than lobsters. This uniquely specialized organism was not similar to any other arthropod. A reconstruction of *Odaraia* in its natural habitat is from Conway Morris's book *The Crucible of Creation,* and is shown in Figure 1.

Figure 1. Odaraia (center) *with other Burgess Shale organisms including Nectocaris* (middle right), *two Pikaia swimming in* upper left, *an annelid worm Canadia (lower left), a Pirania sponge with spicules* (lower right), *a pair of Dinomischus (lower middle) and Ctenorhabdotus* (upper right). *From Conway Morris,* The Crucible of Creation, *Oxford University Press.*[4] *1998. By permission.*

Sidneyia

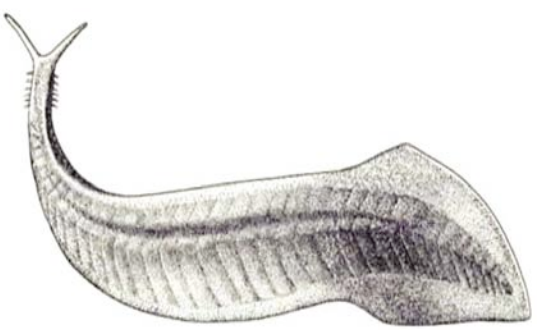
Another organism, *Sidneyia,* most closely resembled a group of arthropods called the merostomes, but it had a number of unique features indicating it was not a close relative of this group. Like other Burgess creatures it tended to be a grab bag of different features. For example, the first four of the nine body segments carried legs similar to those of merostomes, while the last five segments carried walking legs with gill branches. *Habelia* was yet another variant where for the 12 trunk segments, the first six had typical legs, while the last six bore only gill branches.



Sarotrocercus

Sarotrocercus was one of the weirdest of the Burgess organisms. It had large bulbous eyes on stalks, nine body segments with gills but without leg branches, a tail with a tuft of spines at the end, and looked like a ride at Disneyland. *Sarotrocercus* was informally called *Santa Claws* to reflect the large and ferocious pair of front claws.

Wiwaxia is another weird Burgess wonder with no body segmentation and with no modern relatives. Other than the jaw that vaguely resembled a clam, there was nothing else about *Wiwaxia* that resembled other mollusks, living or dead.



Pikaia

Pikaia was the last Burgess organism that Gould described and is one of the most intriguing of the creatures described by Conway Morris. It appears to be the world's first known cordate. Chordates possess a notocord, the precursor of the spinal column which was required for the development of the nervous system.

Figure 2. Anomalocaris has captured a trilobite. In the lower right *is the five-eyed* Opabinia. *In the* lower left *is* Wiwaxia, *and in the* lower middle *are three* Hallucigenia. *The two cup-like organisms at the bottom are Dinomischus. From Conway Morris* The Crucible of Creation, *Oxford University, New York. 1998.* [4] *By permission.*

This makes *Pikaia* a landmark in the history of the phylum to which all the vertebrates, including man, belong. Pikaia was a precursor to us. Gould [1p323] stated:

> …if you wish to ask the question of the ages—why do humans exist?—a major part of the answer…must be because *Pikaia* survived the Burgess [extinction].

Gould [1p160] also stated that:

> Each one [of the Burgess arthropods] seemed to be built from a grab bag of characters—as though the Burgess architect owned a sack of all possible structures, and reached in at random to pick one variation upon each necessary part whenever he wanted to build a new creature….Where was order, where decorum?

In summary, most of the unique Burgess organisms are now extinct. The Burgess organisms that were precursors to later, but eventually extinct, organisms included the trilobites *Naraoia* and *Tegopelte.* The Burgess organisms that were precursors to modern organisms were *Canadaspis* (Crustacea) and *Pikaia* (Chordates)

Evolution is Not Directed

In reflecting on the wonders of the Burgess Shale fossils, Gould mused in *A Wonderful Life* [1p50] that if the tape of time were rewound and the period of the Burgess Shale replayed, the animals who survived and those who became extinct might be totally different and all subsequent life forms could have been different. The point and truth of this mental exercise is that as much as it may appear to have been goal directed toward a magnificent outcome (man), each step of the way was a crap-shoot of random events. The outcome of evolution is not predetermined.

The Burgess Shale fossil bed in Canada provided a treasure trove of fossils from the Cambrian Period. Over a time course of about 10 to 20 million years many modern and fossil animal phyla came into existence and no new phyla developed after that. Over 90 percent of the species became extinct, while others formed the beginnings of multiple modern phyla including chordates from which vertebrates including man evolved. The mechanisms by which the incredible burst of creation and diversity of body forms could have developed so quickly are discussed in the next chapter.

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The God of the gaps was actually a theological mistake. If God is the Creator, he is somehow connected with the whole show, not just the difficult or murky bits of what is going on.

John Polkinghorne
Quarks, Chaos and Christianity [1p22]

Part II

Intelligent Answers to Intelligent Design

There are two ways to respond to the threat to theism posed by the theory of evolution. One is to concede that the scientific evidence for evolution is so overwhelming that it is hopeless and irrational to believe otherwise. Accepting the validity of evolution does not prove that God does not exist. For many the next logical step is too great a leap. That step is that the theory of evolution is totally consistent with a belief in the existence of God if one adopts the view that God created the raw materials for the universe then went on to other more important things and left the creation of multiple life forms to evolution. The situation is illustrated by the joke related by Dembski. [2p38]

> Scientists come to God and claim they can do everything God can do.
> "Like what?" asks God.
> "Like creating human beings," say the scientists.
> "Show me," says God.
> "Well we start with some dust and then"—God interrupts.
> "Wait a second. Get your own dust."

I have included this because it is genuinely funny. However, it also illustrates why, in Part III, I discuss cosmology, since it is related to "getting our own dust."

Having once started things going, one must assume that out of curiosity God occasionally checked in to see what was happening. Of course the alternative that God does not exist is also quite possible. As pointed out in the Introduction, based on Occam's Razor, this seems the more logical of the two theories since it removes from the table the troubling and even more difficult next question, Who created God?

The second way to counter the threat of the theory of evolution is to claim that the scientific evidence for it is so deeply flawed in many of its aspects that we do not need to take it seriously, and yes, God really did create man and the universe. This has become a very popular approach. Five surveys in the United States over the past 20 years consistently show that 45 percent believe God created humans in their present form in the past 10,000 years, 37 percent believe God had a guiding hand in the development of humans, and only 12 percent believe God had no part in the process. Only a third believe Darwin's theory of evolution is well grounded in science. [3]

Respondents were also asked whether they believed more in creationism than in evolution. Of those who chose creationism, 28 percent still felt that humans have developed over millions of years from less advanced forms of life, but that God guided this process. Thus, not all self-avowed creationists reject the basic tenets of the theory of evolution.

There are two groups of detractors or anti-Darwinists—the creationists who believe in the total infallibility of the Bible and literally accept the account of creation as stated in the Book of Genesis, and those who propose the concept of Intelligent Design. The evidence against the young earth creationists' proposal that the earth is less than 6,000 years old is so overwhelming that I refer the reader interested in the evidence against this viewpoint to other books [4-15] and to the National Center for Science Education website www.ncseweb.org. It is not my purpose to respond to every single complaint of the old earth Intelligent Design Creationists. I have chosen only those given the highest visibility. The interested reader can refer to the National Center for Science Education website for responses to issues not covered.

Since young earth creationists believe the earth is young, and since a variety of radioisotope dating methods clearly show it is 4.5 billion years old, the young earth creationists spend a lot of effort attempting to disprove the validity of these dating methods. For those interested in a detailed account of why the creationists are wrong, and a description of the rubidium-strontium isochron dating with its self-calibrating and self-checking results, I refer the reader to Brent Dalrymple's book *The Age of the Earth.* [16] In contrast to these issues, I will answer some of the most relevant questions raised by the Intelligent Design group.

Darwinian Evolution "Just a Theory"

One of the most common objections to Darwin's theory of evolution is that it is "just a theory." In popular usage the concept of "a theory" often implies a rather weakly supported thought. However, in science, the term theory is a much stronger term. In science, theories are proposed, then tested and tentatively accepted or discarded. It is never possible to unequivocally prove that a scientific theory is correct. But theories can be disproved or, as scientists say, falsified. As Karl Popper stated, "We never prove a theory right; we merely fail to prove it wrong." [17] Science is a constantly moving collection of theories where no theory is sacred, but some are more sacred than others because numerous attempts at falsification have failed. Most good theories make a number of predictions. If those predictions turn out to be incorrect the theory is falsified and thus disproved. If the predictions turn out to be correct and if repeated attempts to falsify a theory fail, the theory is considered likely to be correct—but it is still called a theory.

The most famous example of attempting to falsify a theory occurred after Einstein published his famous theory of general relativity in 1915. The effect of gravity on the warping of space predicted that light would be bent as it traveled past the sun. The first attempt to falsify Einstein's remarkable theory was carried out by a group of scientists led by Sir Arthur Eddington. [18]

In 1919 these scientists went to Brazil and Africa to study a total eclipse of the sun. This allowed them to determine if the position of stars behind the sun was shifted because their light rays were bent by gravity when they passed by the sun. They were. Einstein predicted the light would be bent by 1.74 arcseconds. Eddington showed it was bent by 1.79 arcseconds. The minor difference was well within the range of measurement error. The general theory of relativity was not unequivocally proven, but a major attempt to falsify the theory failed. If enough attempts to falsify a theory fail, confidence that the theory is correct begins to build. While it has often been claimed that the theory of evolution is "just a theory," some of the most remarkable advancements and achievements of mankind are still referred to as theories, such as the Theory of Relativity or the Theory of Gravity or the Quantum Theory. One could say that the proposal that the sun will rise in the morning is "just a theory." It cannot be absolutely, unequivocally proven. However, since the sun has risen since the creation of the earth, all 4.5 billion x 365 or 1.64×10^{12} attempts to falsify this theory have failed, giving us confidence that the theory is correct. As discussed in this book, the massive evidence in favor of the Theory of Evolution has given scientists enormous confidence that it is true.

The Intelligent Design group continuously attempts to falsify the Theory of Evolution. In this book I am proposing that evolution is totally capable of explaining the origin of life in the universe and that Occam's razor is best satisfied by the proposal that man created God rather than God created man, since it best answers all related questions, including who created God? The purpose of this book, however, is not just to make this point. Its purpose is to examine the role of evolution in the formation of the two dueling parts of our brain—the part providing us with the capability for rational, analytical thought and the part thirsting for spirituality. Are they compatible? Can we have both? My story is cleaner and more robust if the theory of evolution is not falsified. Thus, I have devoted Part II to answering some of the attempts by Intelligent Design groups to falsify the theory of evolution. I cannot possibly answer all of their objections. Like a pile of cafeteria plates, when one is answered new ones are generated and pop up to take their place. All I hope to do is answer some of the most common objections. Each issue has its own chapter.

If you are already a staunch believer in evolution, you could skip to part III on Cosmology. However, reading the following chapters might allow you to better answer the Intelligent Design claims if you should be called upon to do so.

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Chapter 4

Does The Cambrian Explosion Disprove Darwin's Theory?

Creationists and Intelligent Design proponents present the Cambrian explosion as a shining example of a phenomenon that evolution cannot explain. For them it is a prime example of the creative powers of a supernatural being. This became an exemplar of their cause by virtue of the fact that in Darwin's time (1859) and in Charles Doolittle Walcott's time (1900) knowledge about Precambrian life was non-existent. Not a single well-documented fossil had been found from any time before the Cambrian explosion, and the earliest evidence of multicellular life coincided with the earliest evidence of life. There could not be a better example of the creative touch of a supreme being.

The creationists and Intelligent Designers were not the first to see the hand of God in the Cambrian explosion. The apparent absence of life during most of the earth's history and its subsequent appearance at full complexity posed no problem for anti-evolutionists. Sir Roderick Imprey Murchison, the great geologist who first worked out the record of early life, viewed the Cambrian explosion as God's moment of creation, and read the complexity of the first animals as a sign that God had invested appropriate care in his initial models. [1] Writing five years before Darwin's *The Origin of Species,* he explicitly identified the Cambrian explosion as disproof of evolution ("Transmutation," in his terms), while he extolled the compound eye of the first trilobites as a marvel of exquisite design:

> The earliest signs of living things, announcing as they do a high complexity of organization, entirely exclude the hypothesis of a transmutation from lower to higher grades of being. The first fiat of Creation which went forth, doubtlessly ensured the perfect adaptation of animals to the surrounding media; and thus, whilst the geologist recognizes a beginning, he can see in the innumerable facets of the eye of the earliest crustacean, the same evidences of Omniscience as the completion of the vertebrate form. [2p459]

As reviewed previously, Darwin was forthright in exposing the difficulties of his theory and placed the Cambrian explosion at the pinnacle of his distress. He

acknowledged the anti-evolutionary interpretation of many important geologists and recognized that this theory required an extensive Precambrian record of precursors for the first complex animals. Darwin has been vindicated by the subsequent findings of a rich Precambrian record, most discovered in the recent past. In his book, *Icons of Evolution,* Jonathan Wells[3] presents the following diagram purporting to represent Darwin's theory (top) and the reality of the Cambrian explosion (bottom).

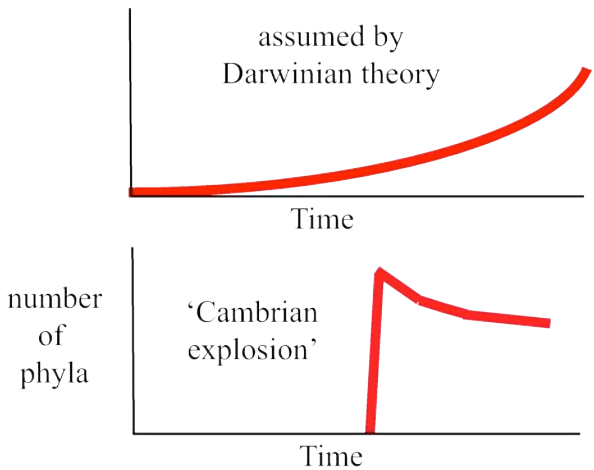


Figure 1. Comparison of Darwin's evolutionary gradualism with the reality of the Cambrian explosion for phyla. From Wells.[3] By permission.

The pattern for the number of phyla has been referred to as an upside-down tree of life and a failure of Darwin's prediction of progressive gradualism with many missing links. There are a number of caveats to this complaint.

First, to the casual reader this pattern gives the impression that all forms of life started with a single burst of creation in the Cambrian period. If this were really the case one might be justified in thinking this was surely proof that a supernatural being touched the surface of the earth and instantaneously brought forth this plentitude of life. However, the time scale for the Cambrian explosion was more like 10 to 20 million years, hardly a single touch. God would have had to linger quite awhile over this type of creation.

Second, note that pattern refers to animal phyla. Phyla are the major subdivisions of life based on body form. As reviewed in Chapter 2 several important groups of organisms such as the bacteria were present for several billion years before the Cambrian Period, again hardly a brief touch. Other forms such as red and green algae, other eukaryotes, soft-bodied invertebrates, "small shelly fossils," and the organisms of the Vendian and Ediacaran periods all proceeded the Cambrian explosion. All combined, based on the fossil record, there were many phyla in existence prior to the so-called Cambrian explosion. These included Proferia, Coelenterata, Nemertina, Echinodermata, Mollusca,

and Anthropoda.[4] Thus, the widely held perception that all of the known phyla came into existence during the Cambrian Period is simply not correct.

Third, molecular clocks produce a tree of life based on the sequence of DNA, RNA and proteins. Such molecular results suggest that most of the major phyla originated long before the Cambrian explosion. Based on molecular clocks from different vertebrate species this diversification began more than one billion years ago.[5-7] Figure 2 is a diagram of the divergence times reported by Wray et al.[5] based on DNA sequencing of seven different genes.

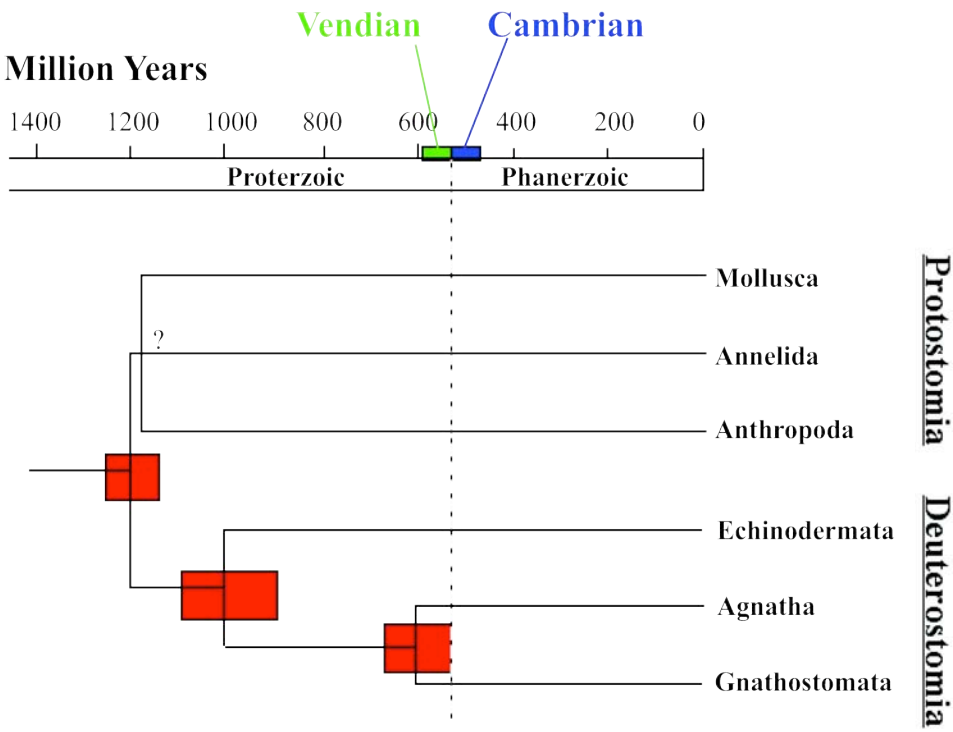


Figure 2. Divergence times for selected phyla. Standard errors are indicated by the red bars. The three estimated divergence times are in agreement with well-corroborated phylogenetic relationships. The chordate-echinoderm and chordate-protostome divergence times are significantly different from each other. From Wray et al. Molecular Evidence for Deep Precambrian Divergences Among Metazoan Phyla. Science. *274: 568-573, 1996.*[5] *By permission.*

The molecular clock shown in Figure 2 agrees with the fossil record that diversification of major phyla began prior to the Cambrian explosion, but this clock also gives an earlier date than that proposed by the fossils record. As such this could represent what Darwin and others referred to as pre-Cambrian "hidden evolution."[8] It could be argued that when only a few genes are examined, the clock may not be accurate. The

clock in Figure 2 is based on seven different genes. However, the molecular clock reported by Wang et al. [6] was based on 50 genes and gave a similar result.

Molecular clock studies based on invertebrates have given more recent times for the formation of bilateral body forms (bilaterians) shown as the first branch of the above tree. Peterson and colleagues estimated that the last common ancestor of the bilaterians arose between 573 and 656 million years ago. Microfossils of the Doushantuo formation in southern China have identified a primitive bilaterian called *Vernanimalcula* (small spring animal) (Figure 3) dating from 580 to 600 million years ago. [9]

Figure 3. Reconstruction of Vernanimalcula, the earliest bilaterian fossil dating to 580 to 600 million years ago. From David Bottjer, "The Early Evolution of Animals," Scientific American. *293: 42-47, 2005. A. Bachar Illustration Design. By permission.*

This time frame was 50 million years prior to the start of the Cambrian explosion. Thus, with a more complete fossil record and the results of studies of molecular evolution, the following more closely illustrates reality.

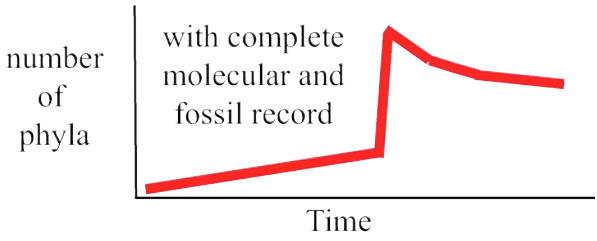


Figure 4. A more-realistic picture of the evolution of the Cambrian "explosion."

This is more like the end of a long slow crawl than a Big Bang or explosion.[10] Long after the Cambrian explosion many millions of species and hundreds of families (two divisions up from species and two down from phyla) continued to evolve. The following figure illustrates the number of new insect and four-legged animal (terrestrial tetrapod) families that evolved from the Devonian to the Tertiary periods.

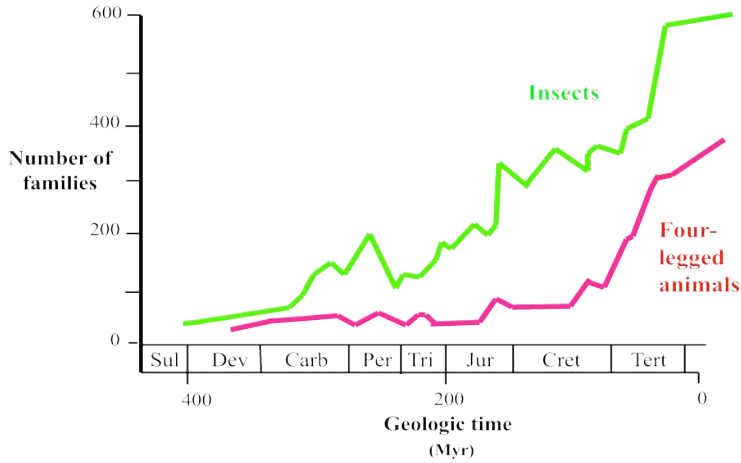


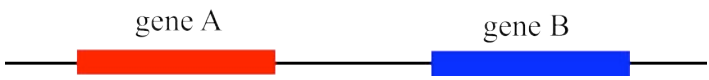
Figure 5. Rapid diversification of families of insects and four-legged animals since the Cambrian explosion.[11, 12]

Again, the pattern in Figure 5 hardly represents a single instant for the creation of all groups of species.

Despite these caveats, it is still necessary to explain how so many different phyla could come on the scene over a relatively short period of time. Gould made a distinction between disparity or the number of body forms and diversity—the number of different species. While diversity continued to increase, as shown in Figure 5, disparity peaked during the Cambrian explosion and then decreased, as shown in Figure 4. Before getting into the details of how the disparity increased so rapidly, it is necessary to present a few basic aspects of genetics relating to gene duplication and unequal crossing over.

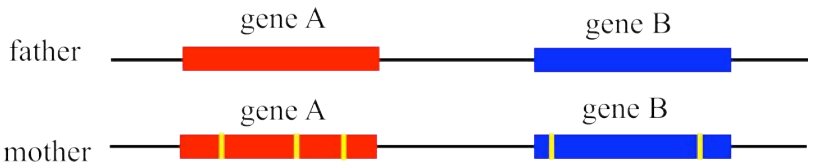
Gene Duplication and Unequal Crossing-Over

The earliest single-cell organisms without a nucleus (prokaryotes) had only a small number of genes, numbering in the low hundreds. Mice, humans and other mammals have approximately 25,000 genes. How does the number of genes increase over time? This is accomplished by gene duplication through a process of unequal crossing over. Early animals started with a single copy of each gene, for example genes A and B.

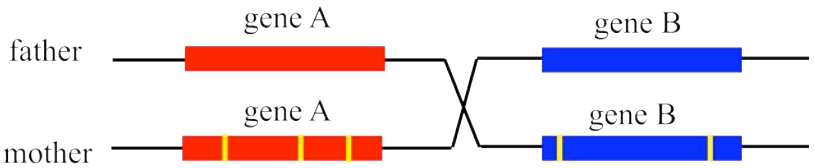


Gene rearrangement. Most eukaryotes are diploid; that is, they possess one set of chromosomes from the mother and one set from the father. Random genetic changes in the sequence of DNA are very common. Sometimes they affect the function of the

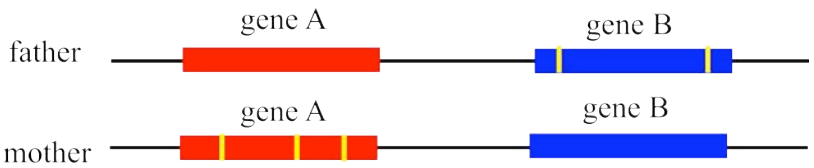
genes; more often they do not. As a result, the sequence of the maternal and paternal genes are often different. These sequence differences are shown by vertical yellow lines.



During *meiosis*, a special form of cell division associated with sexual reproduction, the chromosomes from the mother and father pair with each other. This allows crossing-over between the maternal and paternal chromosomes.

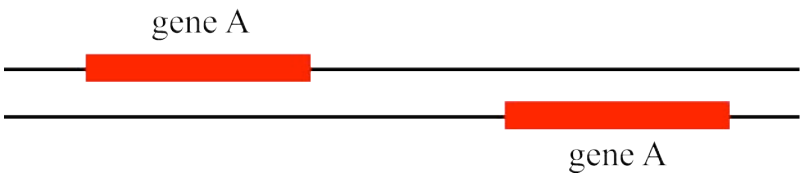


When the resultant products separate into individual eggs or sperm, the genes are rearranged.

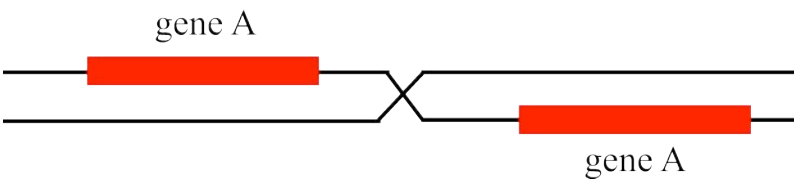


This exchange and rearrangement of genetic information provides a powerful mechanism for increasing the genetic diversity and survivability of life forms.

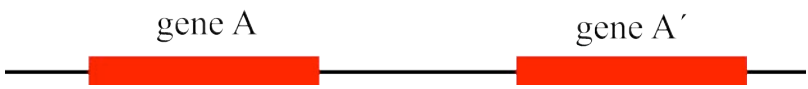
Gene duplication. During meiosis, chromosomes may pair out of alignment to produce the following arrangement:



Now, crossing-over occurs between these two copies of gene A.

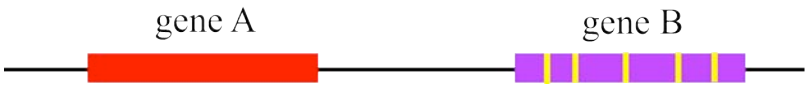


When the two chromosomes are segregated into an egg or a sperm, one has two copies of gene A



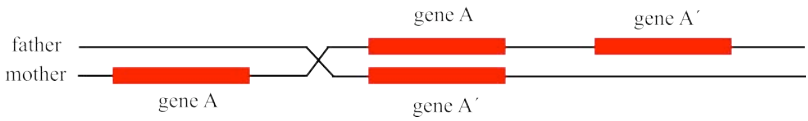
while the other chromosome has none.

If the germ cell missing the gene is involved in fertilization, the embryo will die and the chromosome with the gene deletion is usually lost. On the other hand, if the egg or sperm with the duplicated gene is involved in a fertilization, the resulting organism will now have two copies of the gene A, A and A' and more of the gene product will be produced. If this is of some advantage for the organism, it will be selected and soon the pair of duplicated genes will become fixed in the population. Since the organism still has a normally functioning gene A, gene A' is now free to have multiple random genetic changes that can alter the function of the gene to produce a new gene, B.

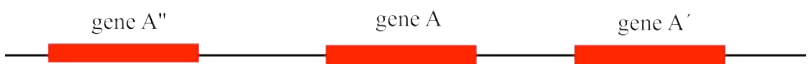


This is how the number of genes increases over evolutionary time. When the DNA of these genes is sequenced, because of the similarity of most of the sequence, the fact that gene A and B were originally one gene *can be deduced even millions of years after the duplication.*

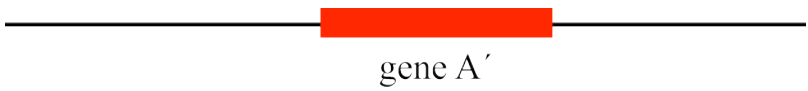
Once a gene duplication of gene A, to A and A' has occurred, the rate of unequal crossing over can now occur much more rapidly. This is because the sequence of gene A and A' is so similar that A can easily but mistakenly pair with gene A'.



Now an unequal crossover between gene A and A,' will produce the following two chromosomes, one with three copies of the gene A,



and one with one copy.



This is the mechanism by which a whole series of genes with similar function can

be distributed into a cluster or family on a given chromosome. Gene duplication is an exceptionally efficient mechanism for rapid evolutionary advance.[13,14] This now sets the scene for a review of the homeotic box, or *HOX*, genes.

The number of genes increased over evolutionary time by gene duplication. The presence of one or more duplicated genes adjacent to each other on a chromosome increases the probability of unequal crossing-over to produce even more gene duplication and gene clusters.

Homeotic Genes

In 1894, the British zoologist William Bateson published a book entitled *Material for the Study of Variations.* In it he had gathered together many examples of mutations that produced what he termed monsters. He was interested in these monsters because he thought that the sudden leaps into new body forms in a single generation might have relevance as a counterpoint to Darwin's slow and gradual changes. These monsters are now known not to be relevant to evolution. He divided the different monsters into those in which the number of repeated parts were altered and those in which one body part was transformed into the likeness of another.[15p46] He called the second group *homeotic* based on the Greek term *homeos,* meaning same or similar.

In 1915, the *Drosophila* geneticist Calvin Bridges discovered the first breeding homeotic mutant that caused the tiny hindwings of the fruit fly to develop into full-formed regular wings when under stress of heat, cold, or anesthesia. He termed this two-winged *mutant bithorax* (Figure 6).

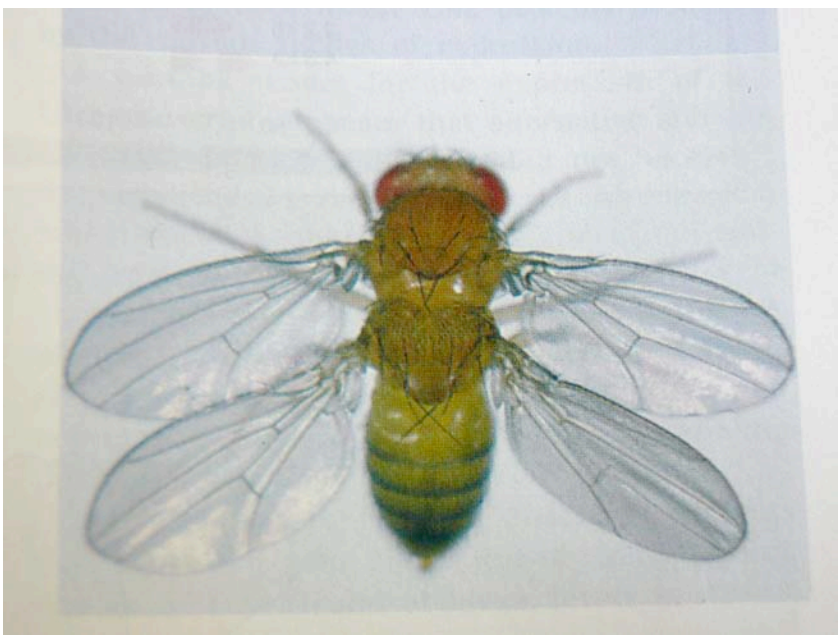


Figure 6. The Drosophila melanogaster *bithorax mutant with two wings. Photo by Dr. Ed. Lewis.*[16]

***HOX* Genes**

The bithorax mutation was studied extensively by the Drosophila geneticist Ed Lewis for which he received the Nobel Prize in 1995. These studies showed the presence of a cluster of duplicated genes that were called the *Bithorax Complex*. There were five genes that controlled the front half of the fly and three that controlled the back half. Remarkably, the order of the genes on the DNA strand was the same as the head-to-tail order of the parts they controlled. Since this formed a box-like set of genes they were termed *Homeo Box,* or *HOX*, genes. The arrangement of these genes and the parts of the body they regulate is shown in Figure 7.

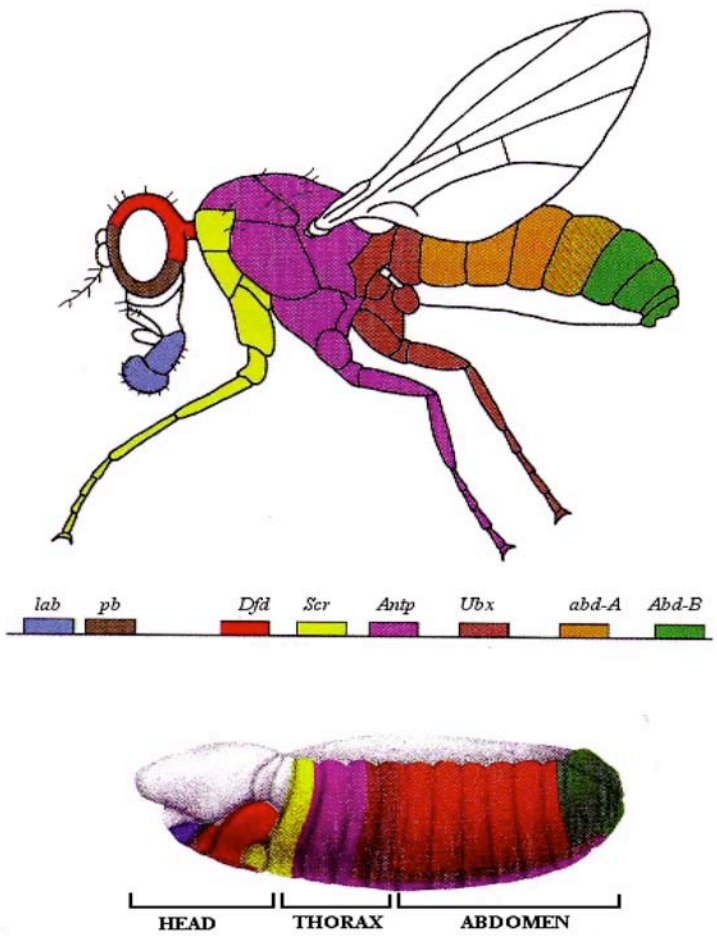


Figure 7. The eight HOX *genes of* Drosophila melanogaster. *From Carroll et al.* From DNA to Diversity, *2001. By permission from Blackwell Science, Malden, MA.* [17]

A further striking aspect of the *HOX* genes was that the same set of genes, in the same order, was present in all animal species from insects to mice to humans. In

mammals, multiple duplications of the entire cluster have produced four sets of *HOX* genes in the mouse. This is shown in Figure 8.

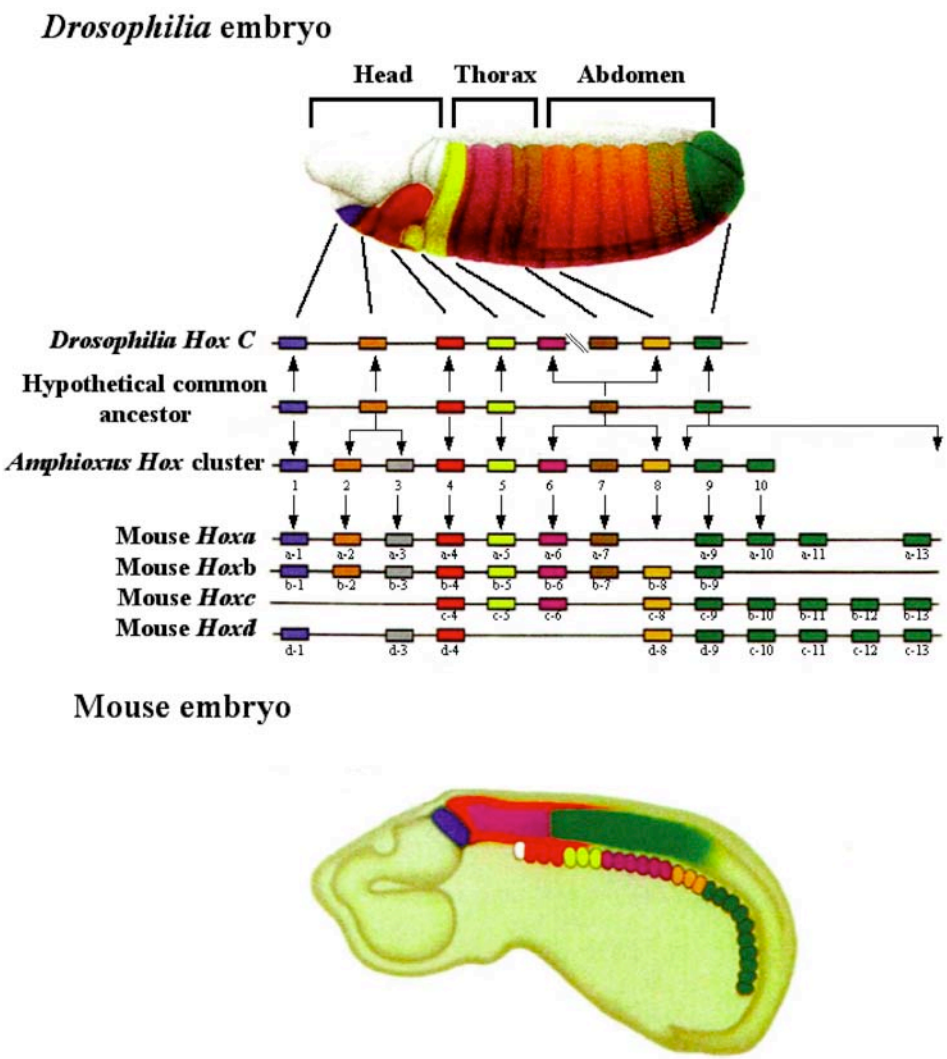
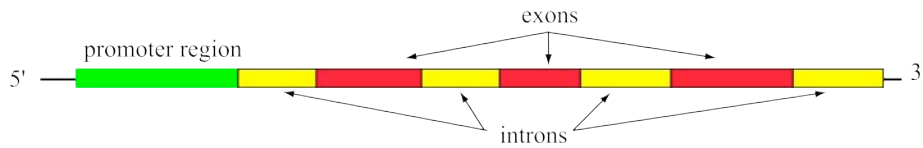


Figure 8. HOX *genes in* Drosophila *and mice. The colors show that the linear arrangement of the* HOX *genes in both* Drosophila *(top) and mice (bottom) corresponds to the same head-to-tail effect of the genes on body form. The middle section shows that the linear arrangement of the* HOX *cluster of genes is the same in* Drosophila *as mice. In mice, the* HOX *cluster has been duplicated four times with retention of the gene order each time. From Carroll, S. B. By permission from MacMillan Publishers, Ltd.,* Nature. *376:479-485, 1995.* [19]

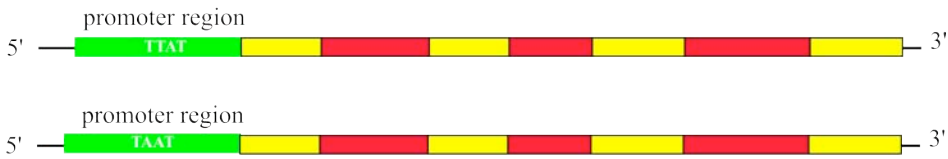
How Do the *HOX* Genes Work?

When the *HOX* genes were isolated and the 1000-plus bases sequenced it was found that each had a segment of 180 bases that were virtually identical across

different species. The sequence of the *HOX* genes was stringently conserved because its function was to bind to a specific DNA sequence. The *HOX* genes are one of a huge group of genes called transcription factors. The specific DNA sequences recognized by transcription factors are in the promoter regions of genes. These regions are at the 5' end of genes as shown in the following diagram.



Promoter regions have a number of regions of specific DNA sequence called promoters. Different transcription factors bind to these different promoters and stimulate or suppress the function of the genes they are associated with. The HOX transcription factors bind to one of two, four base pair DNA sequences 5'-TTAT-3' or 5'-TAAT-3. [18]



Since there are many genes that possess these promoter sequences, there are many proteins whose expression is controlled by the *HOX* clusters. These include other transcription factors, signaling proteins (associated with intracellular communication), and structural proteins. [19]

Switches and Evolution

In the promoter region shown above only a single promoter (TTAT or TAAT) sequence is shown. In reality genes have many different promoters. Some result in an increase in gene activity, some a decrease in gene activity. The level of activity of a gene in a given body organ depends upon the balance of the two. The effect of the homeotic genes on body structure can be altered by mutations that alter these switch regions. These mutations can be insertions or deletions that add or delete whole regions of DNA. *Simply altering the effect of genes that already exist rather than inventing new genes significantly enhances the rate of evolution.*

Other Homeotic Genes

Other homeotic genes are just as striking and informative as the *HOX* genes and like the *HOX* genes they were first described in *Drosophila* and then found to be present in all animals. Pax-6 is associated with eye development across all animals from the flatworms with primitive eyes to humans with very complex eyes. In humans this gene is called *aniridia* because its mutated form is associated with an absence of

the iris. Another homeotic mutant is called *distalless* because its mutated form is associated with a loss of the outer or distal parts of fly limbs. This gene also controls limb structure across a wide range of animals from chicken legs, to fish fins, to legs of marine worms, to the siphons of sea squirts and tube feet of sea urchins. [15p69] A final additional homeotic gene is called *tinman* after the Tin Man in the *Wizard of Oz*, who had no heart. This gene controls aspects of the development of the heart in organisms ranging from insects to man.

Since the homeotic genes regulate many other genes that play a role in body form, any significant change in their sequence would not be tolerated since it would have a highly magnified deleterious effect. This accounts for the highly conserved sequence of homeotic genes over huge periods of time. The homeotic genes predate the evolution of bilaterally symmetrical organisms (bilateria) which occurred in the pre-Cambrian period. *This developmental toolbox was in place before the Cambrian explosion.*

Each body segment has the genetic ability to make a limb. The *HOX* genes do not actually make the limb; instead they either suppress limb development or modify it to create unique types of appendages. [19] The existence of a number of genes affecting body form provides many different targets for genetic variation.

Top-Down Versus Bottom-Up

Phyla are second only to Kingdom in being the broadest taxonomic classification of plants and animals. One of the additional complaints of the Intelligent Designers is that the Cambrian explosion, showing the rapid development of many new phyla, indicates a top-down form of evolution rather than the changes at the level of species or the bottom-up changes envisioned by Darwin. They propose that this falsifies Darwinian evolution. [20p20] In reality, this simply illustrates a lack of understanding of the "developmental toolbox." Evolution progresses by random changes in the sequence of DNA. If the changes happened to occur in *HOX* or *HOX*-like genes, the results will be major changes in body form. The taxonomic method of classification has been in place since the time of Linneaus [21] who placed such major changes at the level of phyla rather than at the level of species. Whether an evolutionary step appears to be top-down or bottom-up simply depends upon which genes are subjected to changes in DNA sequence.

Lysyloxidase

Ohno [4] has pointed out the importance of lysyloxidase in the development of more sturdy Cambrian organisms that make better fossils. One of the unique new aspects of the Cambrian Period is that atmospheric oxygen finally attained modern levels in the atmosphere. The function of lysyloxidase is shown in Figure 9.

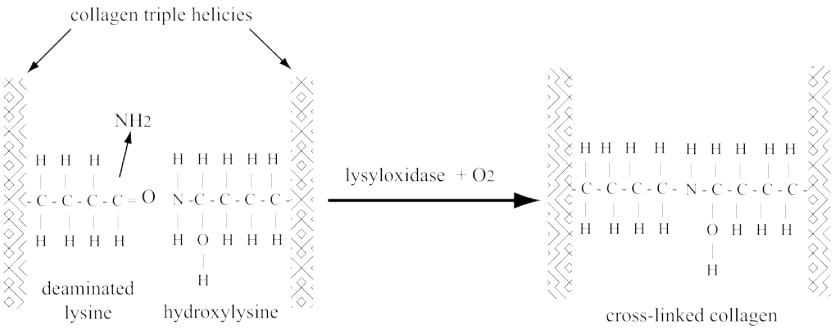


Figure 9. The cross-linking of collagen fibrils by lysyloxidase and oxygen. After Ohno, S. PNAS *93:8475-8478, 1996.* [4]

In the presence of oxygen, lysyloxidase was able to cross-link collagen fibrils, producing much stronger bodies, which made better fossils.

Hemoglobin

A second gene important in using the newly acquired atmospheric oxygen was hemoglobin, a combination of globin and heme. A single mutation allowed hemoglobin to pick up oxygen in the respiratory system and release it in the tissues, paving the way for the development of larger multicellular animals.

A Universal Cambrian Genome

The creationists and the Intelligent Designers foster the notion that the Cambrian explosion involved the rapid development of many organisms all with their own unique set of genes. If this was truly the case, they might have a point. In fact precursor animals all entered the Cambrian period with an almost identical set of genes, which Ohno called the *Cambrian pananimalia genome.* [4] *It was possible to form all of the different body forms by changing less than one percent of the genome*, and there were 10 to 20 millions years for this to occur—well within the capabilities of Darwinian evolution.

The Environment

The existence of a relatively empty environment to expand into is an additional important factor. Quantitative analysis of the morphological characteristics of the Cambrian arthropods showed no unusual degree of disparity, suggesting that the tempo of evolutionary change at that time was not unusually great. [22] Rather, the emergence of the different body plans seems related to an ecological breakthrough into rich, diverse, empty ecological niches. [23]

Evidence There was Plenty of Time for the Cambrian Explosion

We can now return to the central question of this chapter—did the phyla of the Cambrian explosion develop so rapidly that only a supernatural force could have been

involved? There are many reasons to say no.

- The time period of 10 to 20 million years, while short in terms of the totality of geologic time, is still a substantial period. The entire evolution of a wide range of mammals occurred in a comparably short period of time after the extinction of the dinosaurs.
- While the strata suggest the organisms of the Burgess shale evolved over a period of 10 to 20 million years, a comparable collection of many different Cambrian fossils has been found among the Chengjiang fauna found in the Yunnan province of China. The Chengjiang fauna predate the Burgess by 15 million years, thus further extending the time available.
- All of the ten *HOX* genes and the other *homeotic* genes discussed above were in place prior to the Cambrian period. Thus, while the ten-fold duplication occurred by gene duplication, this process was completed and then locked in well over 550 million years ago, [15] prior to the Cambrian explosion.
- All of the animals of the Cambrian Period had virtually an identical genome (pananimalia) and changes in less than one percent of the genome were responsible for all the different body forms.
- It is clear now that the old concept that new genes must evolve to produce new body forms is incorrect. The secret is to teach old genes new tricks, rather than making new genes. [15] Flipping a switch to increase or decrease the expression of an already existing gene is much easier than making a new gene from scratch.
- The many variations in body form and the specialization of appendages for many different functions including feeding, walking, swimming, burrowing, breeding, sensing the environment, and defense were brought about by changing the expression of the different *HOX* genes in different body segments, not by the evolution of new genes.
- Molecular clocks show that while the fossils may have been difficult to find, the actual diversification of many of the phyla occurred as much as a billion years ago, some 500 million years before the Cambrian explosion.
- After several billion years of toil by the prokaryotic cyanobacteria and then the eukaryotic blue-green algae, the amount of oxygen in the atmosphere finally began to approach modern levels. This assisted in the triggering of the diversification of animal phyla in the Cambrian Period. [24] Minor modifications of only a few genes allowed Cambrian animals to utilize atmospheric oxygen. Mitochondria, the main energy producing organelle, had already been in place for over a billion years. [4]
- The few changes listed above allowed the newly evolving organisms to spread into a new virgin ecological space. This also fostered rapid diversification of phyla and species.
- Finally, the pressure of species diversification itself can accelerate further species diversification. [25] This is somewhat analogous to a fusion reaction in an atomic pile—the production of some neutrons promotes the production of more neutrons.

Multiple factors, including the formation of the "developmental toolbox" whereby the same small number of genes control changes in body form for all known animals; the availability of the core tools of this kit over a billion years ago long before the Cambrian Period; the ability of new body forms to be easily derived from old forms by minor modifications of the expression of toolbox genes rather than making new genes; the lack of modern levels of oxygen in the atmosphere until just before the Cambrian period; the availability of an empty ecological niche for the development of new species; and the accelerating effect that species diversification has on promoting further species diversification—all indicate that the Cambrian "explosion" was totally consistent with Darwinian evolution.

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Chapter 5

No Intermediate Fossils Anywhere?

One of the most frequently stated objections to Darwin's theory of evolution by both the new earth creationists and the old earth Intelligent Designers is that the intermediate or transitional species predicted by Darwin do not exist. This is characterized as the "trade secret of paleontology." [1p62] As shown in Chapter 1, Darwin himself addressed this issue. The following is a typical example of the complaints by the creationist and the Intelligent Design group, as illustrated by a Jehovah's Witness pamphlet that stated:

> For evolution to be true, there had to be thousands, millions of transitional forms making an unbroken chain. In reality, such transitional forms are rare.

In answering this complaint, one of the first issues that needs to be addressed is whether intermediate or transitional forms are truly the usual expected outcome of the evolutionary process. It is clear that the classical Darwinian version of evolution, slow gradual transitions with many intermediate forms, so-called *phyletic* evolution, was the expected outcome. But is Darwin's version of speciation necessarily the correct one? Since Darwin's time, as more fossil evidence has became available, three accepted variations on Darwin's theory have developed: the punctuated equilibria of Niles Eldridge and Stephen J. Gould, the allopatric evolution of Ernst Mayr, and finding that the development of new species facilitates the development of additional new species. All three predict the rarity of intermediate or transitional forms.

Punctuated Equilibria Speciation

In 1972, in a book chapter entitled "Punctuated equilibria: An alternative to phyletic gradualism," Niles Eldridge and Steven J. Gould stated:

> The history of life is more adequately represented by a picture of "punctuated equilibria" than by the notion of phyletic gradualism. The history of evolution is not one of stately unfolding but a story of homeostatic equilibria, disturbed only "rarely" by rapid and episodic events of speciation. [2]

The following diagram illustrates the difference between punctuated equilibria and phyletic evolution:

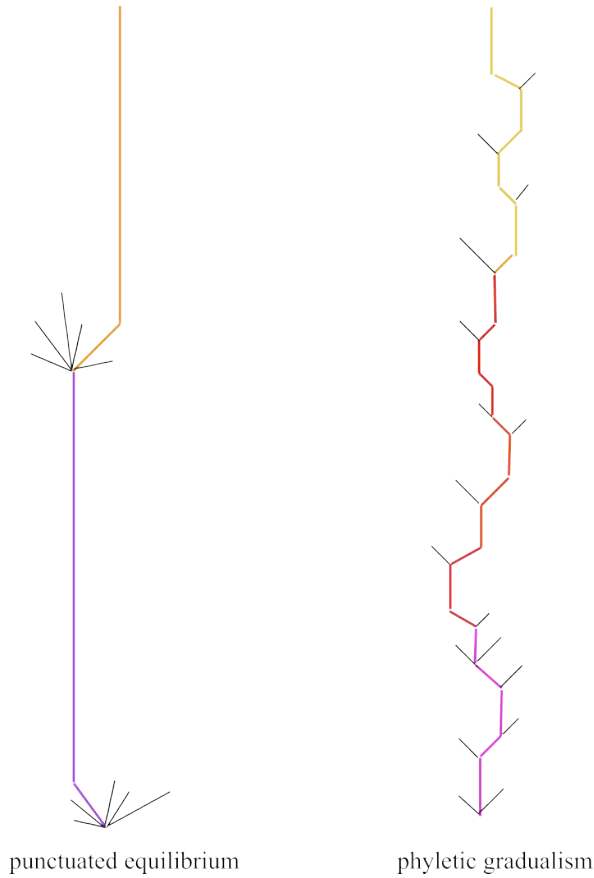

Figure 1. See text.

In punctuated equilibria rapid diversification of species takes place in bursts (punctuation), and one of these species may be selected and remain unchanged for long periods of time (equilibria). By contrast, in phyletic graduated Darwinian-type evolution, a series of gradual changes takes place over time. As represented by the colors, transitional forms are expected to be present in the fossil record for phyletic graduated evolution. For the punctuated equilibria model of evolution they are much harder to find, since most of the time there are no morphological changes. Thus, the frequent apparent lack of intermediate links in an evolutionary line is easier to understand by the punctuated equilibria model where there are often no obvious intermediates. There is just selection of the best twigs of the bush, followed by long periods of equilibria with a species being at peace with its environment.

This subject was brought to the attention of a general scientific audience by a 1980 note in *Science* by Lewin [3] about a conference at the Field Museum in Chicago

entitled *Evolutionary Theory Under Fire.* For Phillip Johnson, the originator of the Intelligent Design movement and of the Wedge philosophy, the apparent contradiction of Darwin's theory of gradualism provided just the fodder he needed to attempt to discredit the theory of evolution. In his book, *Darwin on Trial,*[4] Johnson suggested that Eldridge's and Gould's account of the seemingly instantaneous appearance of new species that then persisted relatively unchanged for long periods of time fit perfectly with how a divine creator would do things.

What Johnson failed to consider was that what Eldridge and Gould had really said was that there was an *apparent* instantaneous appearance of new species over geologic time.[2,5] Geologic time is a very long period, often millions of years. As shown in the following sections, a great deal of typical Darwinian gradualism can occur over such a stretch of time. As one example, 23 different species of elephants evolved over a period of only five million years.[6] When the gradual steps are left out because of an incomplete fossil record, it produces a pattern of punctuated equilibria.

As stated by Gould and Eldridge[5] even his own colleagues fell into this trap.

> …included the misunderstandings of colleagues who, for example, failed to grasp the key claim about geological scaling and misread geological abruptness as true suddenness, and then interpreted punctuated equilibrium as a saltational theory.[7]

By "saltational" they mean the instantaneous appearance of new species through some type of major change or rearrangement of the DNA sequence. In their 1993 review of the punctuated equilibria model, Gould and Eldridge[5] pointed out that most fossil records conform to the pattern of punctuated equilibria.

Speciation by Geographic Isolation

Allopatric speciation refers to the development of new species by geographical isolation in small founder groups at the margin of the geographic range of the parent species or on islands, usually triggered by some type of environmental stress. The famous Darwin finches of the Galapagos are a good example. This form of speciation was championed by Ernst Mayr.[7-10] A critical aspect of this theory is that small isolated founder populations are initially involved. In such small groups, individual new variants with a selective advantage can rapidly become the dominant species. This is somewhat analogous to the punctuated equilibrium model with the caveat that the diversity takes place in a small founder population. If one of these experiments is successful it can result in a new species that will not interbreed if exposed to the parent species. The resultant new species can spread outside the founder group such that new fossil species do not originate in the same place as where their ancestors lived. Allopatric speciation predicts that most variation will be found among samples drawn from different geographic areas rather than from different levels of the rock strata from the same place. Thus, as with the punctuated equilibria model, there would be few or no transitional forms in most fossil strata.

Gould and Eldridge [5] made this point themselves in a 1993 article in *Nature.*

> Mayr's peripatric theory of speciation in small populations peripherally isolated from a parental stock, would yield stasis and punctuation when properly scaled into vastness of geological time—for small populations speciating away from a central mass in tens or hundreds of thousands of years, will translate in almost every geological circumstance as a punctuation…

Allopatric speciation also carries with it an important definition of species as organisms that do not interbreed not because they can't, but because they are geographically isolated from each other. Thus, a species is a specific group of organisms that *in nature* do not interbreed. The *in nature* part is important because two different species can on occasion produce viable offspring, although they are often infertile.

Evolution by the phyletic gradualism of Darwin implies that new species can form even without geographic isolation. This has been termed *sympatric* speciation. Recent studies have suggested that it may in fact, be quite common. [11]

Acceleration of Speciation by Diversity

Studies of species diversity in islands have shown that the increased competition over limited resources due to species diversification promote both the extinction of some species and the development of more new species. [12] On balance, the diversification of species promotes the evolution of even more new species. When squeezed into a framework of geologic time, this important mechanism would contribute to the apparent explosion of new species during punctuations and to the diversification of new species in small founder populations.

All of these mechanisms: phyletic gradualism, sympatric speciation, punctuated equilibria, allopatric speciation, and the acceleration of speciation by diversity operate in different situations. Most would leave behind little or no evidence of transitional forms.

> **Major new models for the evolution of new species have been developed since Darwin's time. One is termed *punctuated equilibria* with bursts of new speciation (punctuations) followed by long periods of no change (equilibria). Another is allopatric speciation or speciation by geographic isolation. A third is the finding that when new species develop it may rapidly accelerate the development of even more new species. All play a role in speciation and would leave behind few if any transitional or intermediate forms. Thus, rather than falsifying the theory of evolution, when speciation takes place by these mechanisms, the absence of transitional forms is the expected outcome.**

All of these models of speciation are likely to play a modifying role for different species, different geologic times, and different ecological niches. If the classical Darwinian model of gradualism plays a role in the development of some species, and is occurring within the geological periods of punctuation, there should be evidence for at least some transitional or intermediate forms. The following is part of a much larger list of examples where such intermediate forms do exist.

Horse Evolution

One of the more frequent examples of an apparent lack of intermediate forms cited by Intelligent Design creationists arises from the story about the evolution of horses. Hogan [13p27] complained that the apparent straight line of evolution from ancient to the modern horse with numerous transitional forms as presented in textbooks is a sham and the true situation, based on additional fossil evidence, is "more complicated and far from conclusive."

In 1876, Thomas Huxley, one of Darwin's most vocal early defenders, was on a speaking tour of the United States. One of his first stops was Yale, where he examined a large collection of horse fossils assembled by the paleontologist O.C. Harsh. Huxley found evidence for progressive stages of evolution, progressing from small 50-million-year-old Eocene "dawn" horses with four toes to the large single-toed horses of modern times. Henry Osborn, the director of the American Museum of Natural History, arranged the original display. It contained just four fossil horses. This displayed a progressive decrease from four toes to one, a change from leaf browsing to high-crowned grazing teeth, and an increase from the size of a fox to the size of a modern horse. Later, more specimens were added and the final result was displayed by the American Museum of Natural History and widely reproduced in textbooks [14] and other museums as a prime example of Darwinian evolution (see Figure 2).

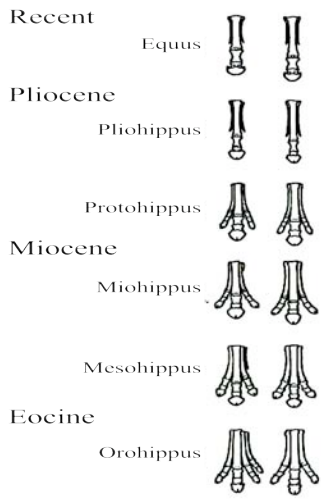

Figure 2. The early proposed smooth, linear path of evolution from small Eocene Orohippus *with four toes to large modern Equus with one toe.*

As more fossils were examined, it soon became clear that the pattern was more complicated. It was more like a bush with many branches than a linear tree with very few branches. The intermediate forms predicted by Darwin were not easy to find. Creationists [13] objected that the displays were wrong and artificially contrived to convey the original concept that Darwinian evolution progressed smoothly from early, presumably more-primitive forms, to later more-advanced forms. This example led many to conclude that evolution theory is flawed because the predicted intermediate forms were not obvious. A more-modern version of the evolution of horses is shown in Figure 3 [15] on the following page.

Modern Equus, shown at the top of that figure, evolved in the past 5 million years in North America. Studies of mitochondrial DNA from horse fossils indicate that in the late Pleistocene there were basically two species of the horse in North America, the true horses of the domestic type, and the "stiff-legged" horses. [16] Over the past 55 million years there was a diversity of extinct genera and species. [17] Rather than a linear increase in size, the horses from 20 to 50 million years ago were all small, ranging from 44 to 110 pounds. After that there was a wide range in size, with some early horses being as large as modern horses, some remaining in the 44- to 110-pound range, and some becoming even smaller over time. The shape of the teeth also varied widely for the past 50 million years, giving clues to whether they were mostly grazers, mixed feeders, or browsers. This variability is also shown in Figure 3.

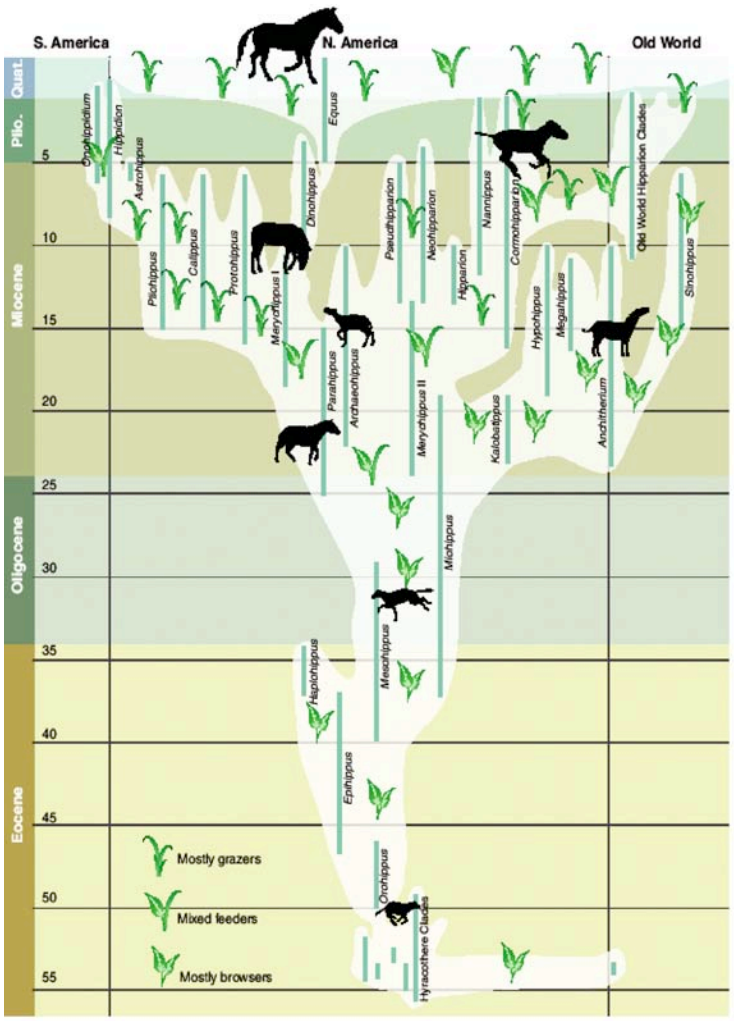

Figure 3. Evolution, geographic distribution, diet and body sizes of the horse family (Equidae) over the past 55 million years. From MacFadden, B.J. Fossil Horses—Evidence for Evolution. Science. *307:2005.* [15] *By permission.*

Thus, in contrast with the linear progression proposed by the early proponents of Darwinism, the evolution of horses is characterized by a more bush-like pattern. The situation was summarized by Rudolf Raff: [18]

> The real record of horse evolution can be portrayed as a bush that at different times sprouted widely varying lineages between browsers and grazers. Most of those lineages became extinct and are not ancestral to the one surviving genus, Equus. The pull of the present as well as expectations of a linear pattern of evolution distorted the picture to make it seem that there had been a majestic 50-million-year evolutionary procession to the modern horse.

Thus, while the early depiction of the evolution of horses was overly simplistic, as knowledge advanced it has become clear that the evolution of horses progressed exactly as predicted by the modern theory of evolution, with much diversity in size, toe patterns, tooth shapes, feeding habits, and many extinct branches. Multiple genetic variations, selection, environmental changes, and geographical isolations resulted in many different species and multiple extinctions. One small twig of this large bush survived to become the modern horse. Thus, rather than being a faulty example of evolution, the story of horse evolution illustrates precisely how evolution works.

While the early depiction of the evolution of horses was overly simplistic, as knowledge advanced it has become clear that the evolution of horses progressed exactly as predicted by the modern theory of evolution, with much diversity in size, toe patterns, tooth shapes, feeding habits and many extinct branches. Multiple genetic variations, selection, environmental changes and geographical isolations resulted in many different species and multiple extinctions. One twig of this bush survived to become the modern horse.

After stating that evolution theory was flawed because there were no intermediate horse fossils, Hogan [13p28] then stated, "The known fossil record fails to document a single example of phyletic (gradual) evolution accomplishing a major morphologic transition and hence offers no evidence that the gradualistic school can be valid." In other words, not only were there no intermediate horse fossils, there were no intermediate fossils for any living or extinct organisms. This purported lack of transitional forms has been a common complaint of both the Creationist and the Intelligent Design community. As shown above, the complaint about the evolution of horses was without merit. Let us examine whether the statement that the known fossil record fails to document a single example of intermediate transitional forms is true. The following are some examples that falsify this statement.

The Burgess Shale

I left one organism out of the Cambrian explosion chapter so it could be discussed here. *Aysheaia* was a third Burgess organism to survive the Cambrian Period. It was one of the most widely discussed Burgess organisms representing the two P's: primitive and precursor.

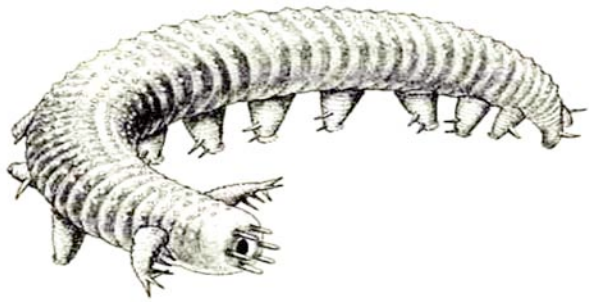

Figure 4. Aysheaia. *A Burgess shale species that may be a non-missing link between worms (annelids) and arthropods. From Gould.* [19]

Aysheaia was most closely related to a small group of modern invertebrates called the *Onychophora,* with characteristics of both annelids and arthropods. As a result it is often considered to be a rare connecting "non-missing link" between two phyla. Although it did not have the jaws typical of modern *Onychophora*, Gould [19] points out that the jaws may have simply evolved later, as occurred with other organisms, making it a true less-developed transitional form. While it is true that transitional forms are rare in the fossil record, *Aysheaia* is a reasonable candidate.

Diatoms

Diatoms are single-celled organisms that contribute to plankton in the sea. They often show remarkably beautiful bodies composed of silica as shown in Figure 5.

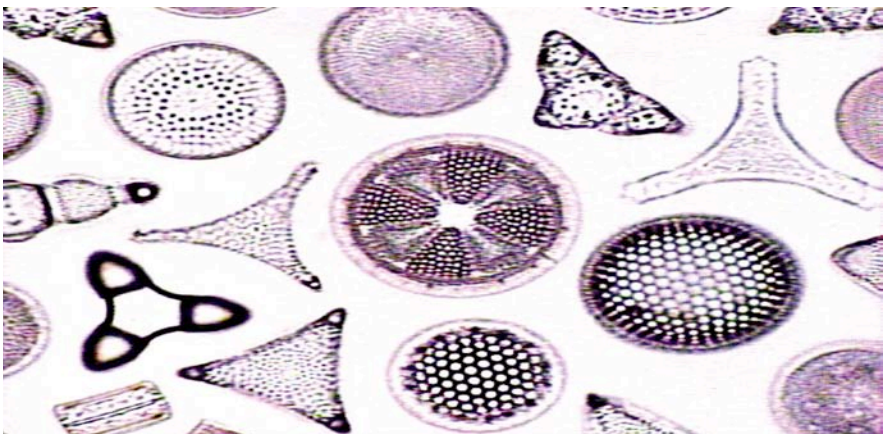

Figure 5. Diatoms [20]

Because of this mineral skeleton, they leave an excellent fossil record. Figure 6 shows such a fossil record for a diatom called *Rhizosolenia* between 1.6 and 3.4 million years ago. [21-22]

Approximately 3.1 million years ago a single ancestral species split into two species. One of the differences between the two species can be measured by a feature of the silicon skeleton, namely the height of a specific glassy (hyaline) area of the cell wall. This unusually complete fossil record shows the presence of transitional fossils of intermediate and decreasing height of the hyaline area between 3.1 and 2.7 million years ago, eventually forming a second species *Rhizosolenia bergonii* (solid dots). The height of the hyaline area of the parent species, *Rhizosolenia praebergonii* (open dots) remained constant.

This is a uniquely complete fossil record. Imagine if we only had fossils on the parent species from 3.3 million years ago and of the parent and derived species from 2.6 to 1.6 million years ago. This would mimic punctuated equilibria whereby new species arise by a split in paternal species seemingly almost instantaneously, in geologic time, and subsequently undergoing little change. With such an incomplete record it is also easy to imagine a creationist or Intelligent Designer complaining that since there were no intermediate species, Darwinism was falsified. This and some of the other examples in this chapter show that when the record is complete, transitional forms are indeed present.

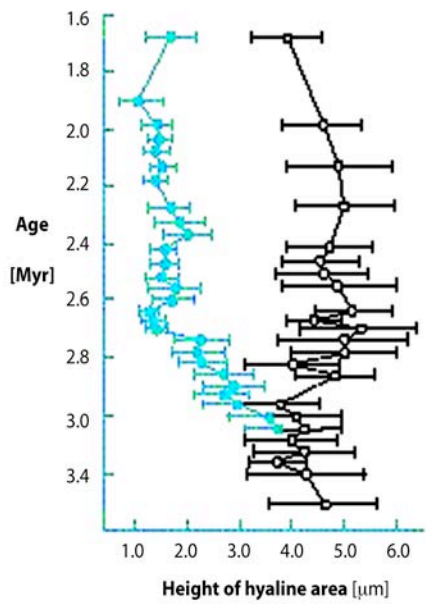

Figure 6. The evolutionary split of the diatom Rhizosolenia praebergonii *into a second species* Rhizosolenia bergonii *from 3.1 to 2.7 million years ago. Cronin & Schneider.* Trends in Evol Biol and Ecology. *5: 275-279, 1990.* [22, 23]

Mollusks and Species Extinctions

Jean Baptiste Lamarck (1744–1829) proposed the view that animals were able to pass on acquired characteristics. While this has subsequently been shown to be untrue, a number of Lamarck's ideas predated Darwinian evolutionary thought. [7] These ideas included the proposal that animals show a graded series of perfection or complexity, that these changes take place very slowly over enormous periods of time, and that this is not a problem because, for nature, time has no limits. Some of these conclusions were based on the fact that Lamarck took over the mollusk collection of the Paris museum after the death of the prior curator. The collection included both living and fossil mollusks. He found it was possible to arrange these specimens into a virtually unbroken phyletic series of species from the Tertiary period to modern living organisms. This led to the inescapable conclusion that many other animals had also undergone a slow and gradual change

throughout time.[8] On the other hand, Williamson[23] described a well-documented series of mollusk faunas from the late Cenozoic. The evolutionary patterns in all lineages conform to the punctuated equilibrium model, and no gradualistic morphological trends occurred.

While Lamarck seamlessly integrated extinct and living species of mollusks into a phyletic series, for many eighteenth-century biologists the concept of extinct species was considered to be incompatible with the perfection and benevolence of God. If God's creations were all perfect they would not become extinct and through His benevolence He would not allow species to die out. Lamarck solved this problem by assuming that animals did not become extinct, they just gradually changed into other forms. Evolutionary change was then the solution to the problem of extinction. Lamarck recognized that the earth's environment was constantly changing. For a species to remain in harmony with its environment and thus avoid extinction, it had to constantly change. This is distinct from Darwinism where environmental changes led to extinctions and only natural selection of those individuals with advantageous mutations survived to form new species. For Lamarck and his contemporaries, and for church doctrine, extinction was impossible. For Darwin it was a necessary aspect of evolution.

Trilobites

Peter Sheldon, from the department of geology at Trinity College in Dublin, Ireland, reported his detailed studies of the fossil record of 15,000 trilobites from central Wales. As implied from the title of his *Nature* paper,[24] *Parallel gradualistic evolution of Ordovician trilobites,* he observed many intermediate trilobite forms occurring during this evolutionary period. Three of the eight trilobites reported are shown in Figure 7.

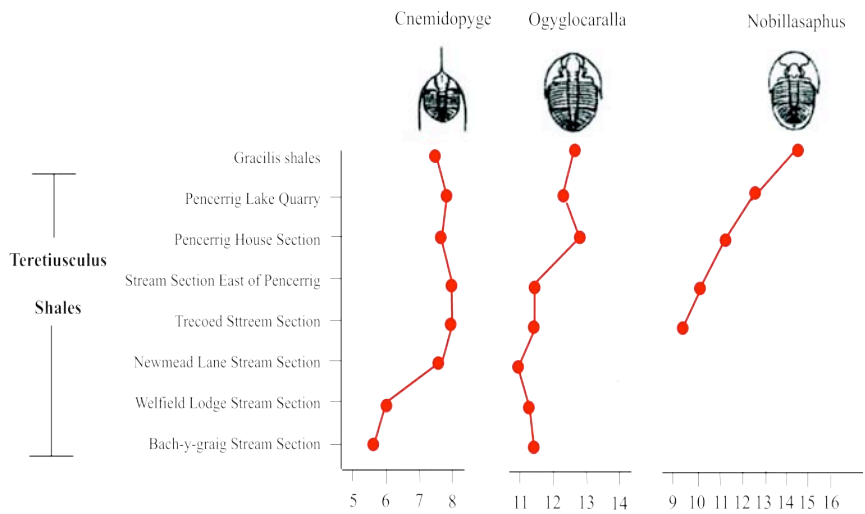

Figure 7. Three of the eight trilobite lineages reported by Sheldon showing parallel gradualistic evolution of Ordovician trilobites. Reprinted by permission from MacMillan Pubishers. Nature. *330:561-563, 1987.*[24]

This clearly shows a slow progressive change over time with different rib counts for these three species, as well as the other five species not shown. Since Sheldon implied that many cases of apparent punctuated equilibria might show similar transitional forms if a detailed fossil record could be examined, his report resulted in a spirited debate with Eldridge and Gould.[25] However, as is often the case with scientific debate, all sides possess part of the truth. Some species evolve by a pattern of punctuated equilibria, some by allopatric speciation, and some by phyletic gradualism. If the precise fossil beds are discovered that present the full local details of the evolutionary experiment, it is likely that intermediate transitional forms will always be present.

Sea to Land

One of the greatest leaps in the evolution of vertebrates was the transition of animals that swam in the ocean to those that walked on land. This momentous event occurred in the Devonian period. The fossil *Acanthostega gunari* is a remarkable example of an intermediate form for this progression. It had internal gills, a fish-like skull and extremities, but was a land-based amphibian with lungs for breathing air.[26] An additional stage of this transition from sea to land was provided by the finding of a fossil fish *(ANSP 21350)* with fingers.[27,28] This fossil represented the intermediate condition between the primitive steering and braking functions of fins and a land-based walking gait. The relationship between *Acanthostega, ANSP 21350,* and other creatures in this progression are shown in Figure 8.

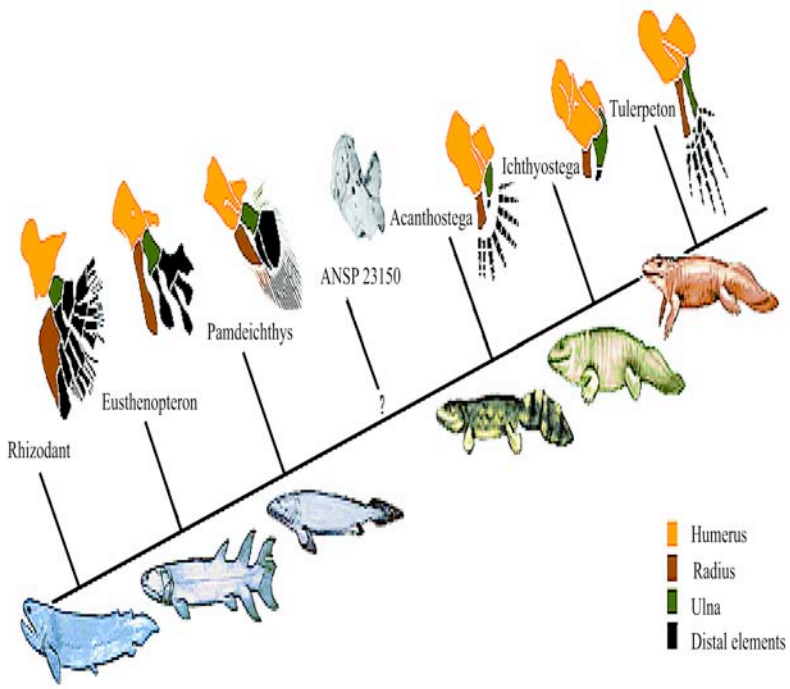

Figure 8. Progression of bone structure from fins to land based four-footed animals (tetrapods). Diagram from J. A. Clack. From Fins to Fingers. Science. *304:57-58, 2004.*[29] *By permission.*

Subsequent reports identified entire skeletons of a transitonal species called *Tiktaalik roseae* with many characteristics of both fish and land-based amphibians.[30–31]

Land to Sea

One of the creationist's texts, *Of Pandas and People,*[32p100] states:

> The absence of unambiguous transitional fossils is strikingly illustrated by the fossil record of whales. By and large evolutionists believe that whales evolved from a land mammal. The problem is that there are no clear transitional fossils linking fossil land mammals to fossil whales.

In 1994, Behe[33] also challenged evolutionists to produce transitional forms for the Eocene period of migration of land animals into the sea to produce whales. In the same year, Gould[34] reported that three such species had already been discovered. One of these is the *Ambulocetus* whale.[35] Figure 9 shows *Ambulocetus* standing on land (A) and at the end of a power stroke during swimming (B).

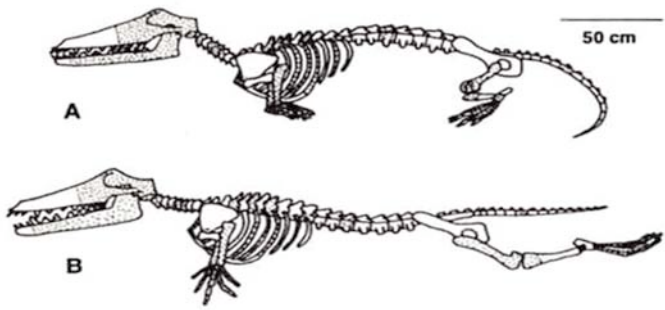

Figure 9. Reconstruction of Ambulocetus *whale standing on land (A) and at the end of the power stroke during swimming (B). Thewissen, et al.*[35] *By permission.*

This surely represents one of the shortest intervals between an anti-evolutionist claim that transitional forms do not exist and paleontologists finding the intermediates.

From Meat Eater to Leaf Eater

An intriguing interaction between a black market fossil dealer and a legitimate academic paleontologist[36] resulted in the discovery of a missing link between meat-eating (carnivorous) and leaf-eating (herbivorous) dinosaurs.[37] The new species *Falcarius utahensis* had five-inch claws consistent with carnivorous habits. However, instead of the serrated teeth of carnivores suited to slashing flesh, *Falcarius* had spoon-shaped teeth ideal for shredding plants (Figure 10). It was found in a massive fossil bed at Green River, Utah. The dinosaur's shift in diet may have been spurred by the advent of flowering plants. This illustrates again how changes in the

environment result in evolutionary changes in animal structure. "It gives us amazing documentation of an evolutionary shift." [34]

Figure 10. Falcarius utahensis. *Illustration by Mike Skrepnick, University of Utah. Kirkland, J., et al. A primitive therizinosauroid dinosaur from the early Cretaceous of Utah. Reprinted by permission from MacMillan Publishers, Ltd.* Nature. *435: 84-87, 2005.*

And the list goes on and on. Intermediate fossil organisms transition between reptiles and birds, reptiles and mammals, and other taxonomic groups have also been described. Many of these intermediates have been found only recently. The finding of these intermediate fossils validate Darwin's assumption that in many cases "missing" intermediates would be found with time. They increasingly have been.

While intermediate or transitional forms are commonly missing, when the fossil record is very complete, the intermediate forms are often observed. When all of the above observations on the different mechanisms of speciation are considered it is clear that the apparent lack of some intermediate forms does not disprove the theory of evolution.

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Chapter 6

Not Enough Time?

A common complaint of creationists and the Intelligent Designers is that the mutation rate for advantageous mutations is so small that even the more than 3 billion years that life has been present on the earth is not enough to allow for Darwinian selection of advantageous mutations. The following is an example of this line of thought.

Based on the population frequency of a number of rare genetic disorders it has been estimated that the average deleterious mutation rate in humans is 10^{-4} or 1 in 10,000 to 10^{-6} or 1 in a million per generation. [1] Since this technique is based on the presence of disease, by definition all of these mutations are deleterious. As a specific example, Hogan [2] cites the case of the human cholesterol receptor gene located on chromosome 19. It consists of 45,000 nucleic acid base pairs and a coding sequence producing a protein of 772 amino acids. Over 350 mutations of this gene have been described. Again, since the case finding (ascertainment) was based on the presence of disease, none of them were beneficial.

This problem of biased ascertainment can be bypassed by performing epidemiological studies in which randomly selected members of the population are chosen for study, independent of disease. Such studies have been performed for many genes and many species. They show that the vast majority of mutations are neutral, that is, they are neither advantageous nor deleterious. Deleterious mutations are the next most common, and beneficial mutations are rare, but do occur.

If we take the average rate of all deleterious mutations as 10^{-4} or 1 in 10,000 generations per gene, the number of advantageous mutations per gene would be at least a thousand times less or 1 per 10,000,000 generations per gene. Humans and most other vertebrates have approximately 25,000 genes. If we assume that 1,000 of these could be the site of a beneficial mutation that would further the evolution of the species, this requires the passage of 10,000 generations before a beneficial mutation occurs. Since the average generation time for humans is approximately 20 years there would be one advantageous mutation per 200,000 years. Since many dozens of beneficial mutations would be required, it could be suggested, as the Creationists have, that the development of humans by Darwinian evolution is impossible.

One could argue that evolution by rare advantageous mutations is still possible for other organisms with a much shorter generation time. A twenty-fold decrease in generation time or one generation per year would help. A generation time of hours to

days, as is typical of many prokaryotes, would be optimal. Some have argued that the ratio of beneficial to deleterious mutations is as high as 1/10,000 to 1/million per gene, [3p127] further exacerbating the problem for species, like humans, with a long generation time. Whether valid or not, it is claimed that advantageous mutations are too rare to allow for speciation by Darwinian selection. As a result Darwinian evolution is falsified and by default, a supreme being had to be responsible.

Well, not so fast (or I should say, not so slow). This line of reasoning ignores some of the most exciting recent advances in molecular genetics. There are two major types of genetic variation based on prevalence in the population—mutations and polymorphisms. Variations are called mutations when they are rare and occur in less than one percent of the population, usually in the 1-in-a-thousand to 1-in-a-million range. Variations are called *polymorphisms* when they occur in more than one percent of the population.Two major types of genetic variations are shown in Figure 1.

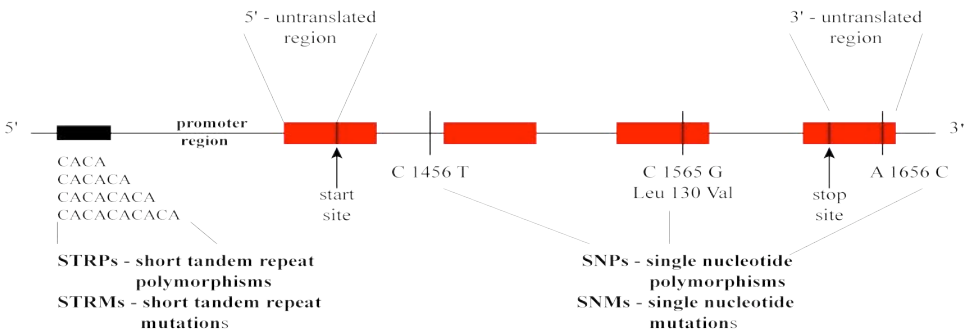


Figure 1. Two common types of polymorphisms. The exons containing the coding sequences are in red.

The first type of polymorphism involves single nucleotides. They are called single nucleotide polymorphisms (SNPs), if they are common and single nucleotide mutations (SNMs), if they are rare. The second type of polymorphism involves short repeated sequences. They are called short tandem repeat polymorphisms (STRPs), if they are common, and short tandem repeat mutations (STRMs), if they are rare. On average a SNP variant occurs every 200 base pairs along the entire DNA sequence of the genome. Since there are 3 billion base pairs in the human genome, this represents 15 million variants per genome. I will first discuss the SNPs and SNMs.

SNPs and SNMs. *Neutral* mutations or polymorphisms occur when a single base pair variation occurs in a relatively unimportant part of the gene such as an intron. A neutral variant is shown in Figure 1 as a change from a cytosine *(C)* to a thymine *(T)* at position 1456 in an intron of this gene. It is neutral becaue introns do not code for proteins. A neutral variation can also occur in the coding or exon regions of the gene if it does not result in a change in the amino acid sequence. This happens when the variation occurs in the third or redundant portion of the amino acid code. For example, refer to the genetic code in chapter 1. A T > C mutation or polymorphism resulting in a change from a CTT to a CTC would be neutral since both triplets code for leucine (L). Mutations that do produce a change in the amino acid sequence of

the protein can also be neutral if that change has no effect on the organism (no phenotypic effect). Variations in the 5' [exclusive of the promoter] and 3' untranslated regions are also likely to be neutral since this is a non-coding region of the gene. SNMs can also be neutral.

Deleterious single nucleotide mutations occur when a SNM has an adverse effect on the function of the gene. This adverse effect can occur when the mutation changes the amino acid sequence of the protein and that change has a negative effect on the health of the organism. This is illustrated in Figure 1 by the C->G (guanosine) SNM at position 1565 resulting in an amino acid change from Leucine *(Leu)* to Valine *(Val).* Deleterious mutations can also occur when an SNM is in the promoter region and alters the expression of the gene to the extent that it has a negative effect on the health of the organism. Since there is selection against deleterious mutations, they almost never become common enough to be polymorphisms.

Advantageous SNMs or SNPs can occur when the variant is in the promoter region and changes the expression of the gene in a positive fashion, or when the variant changes the amino acid sequence of the protein in a way that increases the viability of the organism. It is the advantageous SNMs that the Intelligent Design theorists refer to when they complain that the low rate of advantageous mutations falsifies Darwinian evolution.

STRPs and STRMs. STRPs are key to understanding many aspects of evolution and other aspects of genetics. What are they?

In the 1960s many experiments were performed in which DNA from a variety of organisms was split into its two strands (denatured) by heat. The strands were then allowed to come back together (renature) and the rate of this process was followed. Since there was so much DNA in the genome (3 billion nucleotides), it was anticipated that it would take a very long time for complementary strands to find each other and thus this should be a very slow process. Surprisingly, it was found that a large percent of the DNA renatured very quickly. The only explanation was that some sequences were repeated thousands of times. This, appropriately, was called *repetitious DNA*.

There are a number of different types of repetitious DNA also known as satellite DNA. Two of the types are called minisatellites and microsatellites. In minisatellites the length of the repeat sequence ranges from six to 65 base pairs. In microsatellites the length of the repeat sequence ranges from two to five base pairs. Since different individuals have different repeat lengths and since they are common, both minisatellites and microsatellites occur as short tandem repeat polymorphisms, or STRPs. These have also been called variable number tandem repeats or VNTRs. I will discuss the microsatellites.

Microsatellite DNA. The most common repeat sequence in microsatellites is CA/GT, as shown in Figure 1. Each different size is called an allele. The following are some of the important characteristics of the microsatellite STRPs.

- *Very polymorphic.* The number of different-sized alleles at a given STRP can vary from two to dozens. Thus, the different alleles of a CA two base pair repeat

polymorphisms would be CA, CACA, CACACA, CACACACA, CACACACACA, etc. Since different individuals carry different common alleles this makes the STRPs the most polymorphic of the genetic variants. Thus, while the SNPs usually have only two variations or alleles in the population, STRPs have many alleles.

- *Very Common.* STRPs are very common with hundreds of thousands being present in the human genome. One to many are associated with each gene. They are usually clustered at the 5' end of the gene where most of the regulation of gene activity occurs.
- *Regulate gene function.* In our own laboratory we examined the possible association between STRPs at a number of genes and various human behaviors. One of the genes we examined was monamine oxidase A *(MAOA)*. The *MAOA* enzyme plays a role in the breakdown of several brain neurotransmitters. The relationship between the different allele size groups of a STRP at the *MAOA* gene and a score for manic behavior is shown in Figure 2.

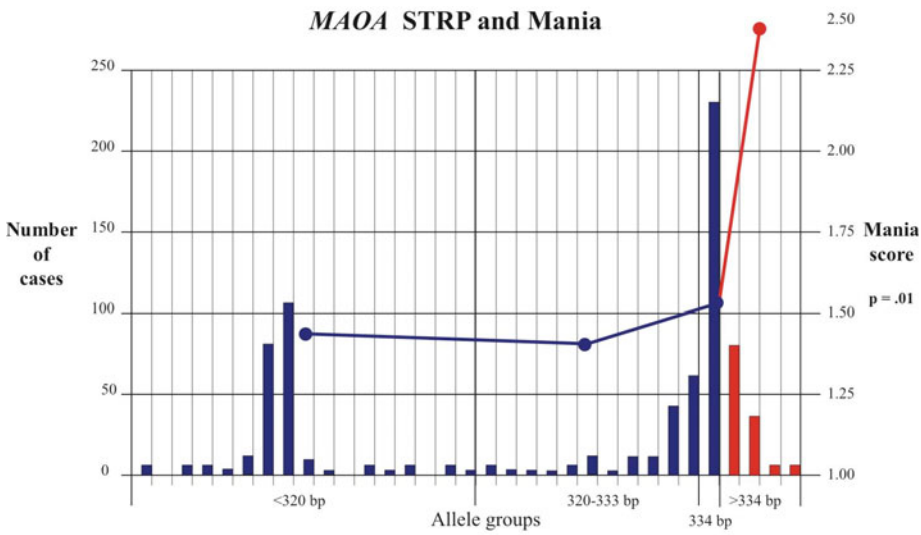


Figure 2. Relationship between the mania score and four different size groups of the MAOA *STRP. From Comings et al.* [4]

This shows that the mania score was fairly constant across several size groups of the MAOA STRP, except the group with the longest size repeats where the score was much higher. This and many other lines of evidence indicate that the STRPs play a role in regulating the rate of expression of the genes they are associated with. [4] The longer alleles may be associated with a greater (or lesser) degree of expression than the shorter alleles. Since each bar in Figure 2 represents a different allele, this also shows how polymorphic the STRPs can be.

- *Gene regulation occurs over long distances.* One of the most remarkable findings about STRPs is that not only do they regulate the expression of genes they are

adjacent to, they can also regulate the expression of other genes "downstream." Because of the potential importance to understanding diabetes, one of the most intensively studied sets of STRPs are those associated with the *insulin* gene. Studies by Paquette and colleagues[5] showed that the effect of STRPs on gene function may extend across several genes. This is illustrated in Figure 3.

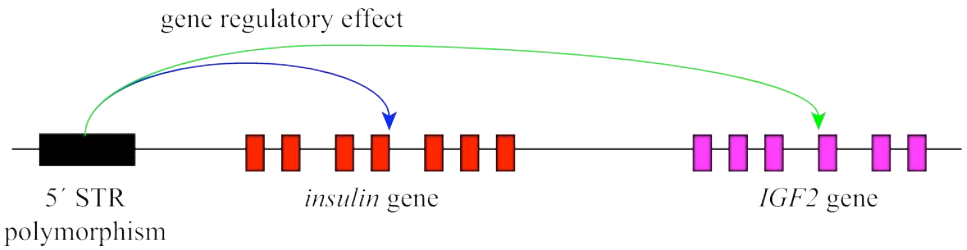


Figure 3. The STRP 5' to the insulin gene not only regulates the expression of the insulin gene, it also regulates the expression of the IGF2 gene 3' downstream. From Paquette et al.[5]

This shows that the 5' STRP not only regulates the expression of the *insulin* gene, but also regulates the expression of the insulin-like growth factor 2 (*IGF2*) gene, 3' downstream from the insulin gene. This indicates that not only are there many different levels of expression of a given gene and different levels of expression may also occur because of the effect of more distant STRPs. On the basis of these findings it is clear that the old idea that a gene occurs in two states, either "on" or "off," is wrong. Instead, most genes occuring in the population are set at many different levels of expression. This is illustrated in Figure 4.

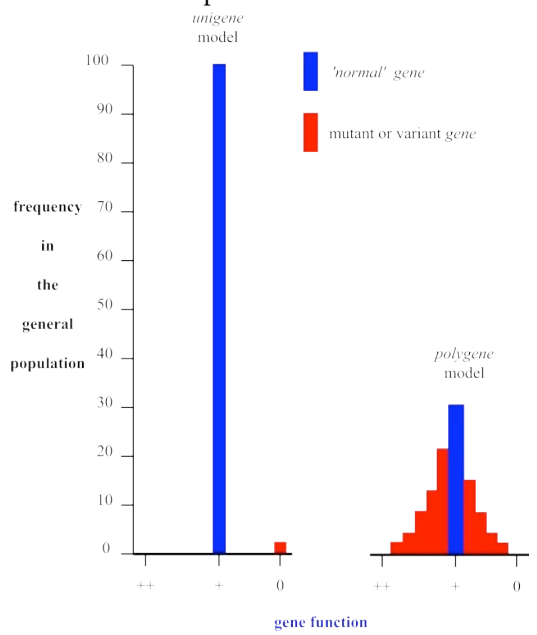


Figure 4. Unigene versus the polygene model. See text. From Comings.[6]

The diagram on the left illustrates the old concept that genes in the population are set at a specific "normal" level of expression, or if a deleterious mutation occurs, no expression. The association of genes with highly polymorphic STRPs, where different lengths of repeats are associated with different levels of gene expression, indicate that genes are actually present in the population at many different set levels of expression.

- *Very high mutation rate.* The mutation rate for single base pairs averages 10^{-9} or 1/billion per locus per generation.[7] By contrast, the mutation rate for microsatellite STRPs is much higher, in the range of 10^{-4} to 10^{-3} (1/thousand per locus per generation).[8-12] The mutation rate is related to the length of the repeat size, the longer the repeat the higher the mutation rate.[10-12] In some cases mutation rates in humans and other species have reached as high as 1/25 to 1/100/locus/generation.[11] *Thus, the mutation rate in STRPs is routinely a million to ten million times greater than for SNMs.*

  Mutations causing an increase in the number of dinucleotide repeats are more common than mutations causing a decrease in the number of dinucleotide repeats, up to a point. Mutations in very long repeats tend to decrease the number of repeats, thus preventing the progressive expansion of these polymorphisms.[12] The rate of mutation is also related to sex. In humans the mutation rate is five times faster in males than in females.[8,9] This sex difference is less striking in other species.[11]
- *STRP mutations are caused by replication slippage.* The very high mutation rate in STRMs compared to STMs is due to the fact that they have a unique mechanism of mutation—replication slippage.[12] This is due to the presence of loops in one of the DNA strands, due to the repeat structure of the STRPs. This in turn results in a deletion or insertion of one or more repeats during the DNA replication process. As a result, the mutation rate is related to the number of cell divisions that have occurred. In human males, production of sperm requires many more cell divisions. As a result, there is a higher mutation rate in males.
- *STRPs are present in many species.* STRP are present in humans, primates, dogs, turtles, lizzards, insects, and other species[11,12] indicating they have been present over long periods of evolutionary time.

Implications for evolution. By now the reader should appreciate the enormous significance the STRPs have for understanding the process of evolution and how the complaints of the Intelligent Designers that the beneficial mutation rate is too low to allow for evolution to occur are invalid. The mutation rate for STRMs is up to 10 million times faster that for SNMs. However, the story is still more elegant. I was so impressed with the implications of STRPs for evolution that in 1998 I stated the following:[4]

> Evolution may not need to wait for mutations; they are always there. One of the tenets of evolution is a dependence upon the occurrence of just the right rare mutations that instead of being deleterious to the species, improve it, and allow selection to produce a new and better adapted

species. This leaves open the question of how such rare events, i.e., mutations that affect the right gene, are advantageous instead of deleterious, happen at the right time, and have occurred often enough to provide for the rich diversity of species.

The concept of micro/minisatellite polymorphisms providing many alleleomorphic functional variants of each gene eliminates the need for this improbable sequence of events. Thus, new mutations or alleles do not have to occur, they are already present, and in great abundance and affecting most genes. It is not necessary for that rare advantageous mutation to just happen to occur at the right time and in the right gene, since all genes come in a rich array of functional variants. What is necessary to drive evolution is an environmental or ecological change to fuel the selection of a given set of genes better suited for the new environment. As an example, the evolution from primates to *Homo sapiens* required many different changes, including standing upright, thumb-finger opposition, the development of speech centers, the expansion of the frontal lobes, and many others. There is evidence that a number of different hominid species were simultaneously and independently undergoing these changes.[13] To accept that multiple advantageous new mutations of many different genes just happened to occur in the right temporal order, and in several different lineages, is difficult. However, if all the necessary mutations were already present, and environmental changes selected for the polygenic sets that were most advantageous, the parallel progression in multiple lineages is more readily understandable. This is not meant to imply that exon mutations in some critical genes do not also play a role in evolution, only that the presence of many functional alleles associated with micro/minisatellites may be a better explanation.[4]

The only addition I would now make is that because of the very high mutation rate of STRP loci, there could be selection for both new mutations and old variants when environment changes or other selective forces occur.

A number of unique characteristics of short tandem repeat polymorphisms (STRPs) make them uniquely suited to play a central role in evolution. These characteristics are:

- **Very variable (polymorphic) in different individuals in the population**
- **Very common, such that one to many STRPs are associated with each gene**
- **Occupy a preferential location at the 5' end of the gene, the usual site of gene regulation**

• Have a long-range of effect on gene regulation extending over more than one gene
• Can rapidly generate variation by replication slippage
• Have an extremely high mutation rate of one to 10 million times that of single base pair mutations
• Play an important role in the regulation of expression of the genes they are next to

As a result of these features there are a large number of pre-existing variations already present in the population. Potentially beneficial mutations and variants already exist waiting to be selected when changes in the environment call for them.

Even if an appropriately beneficial variant is not already present, the very high mutation rate can quickly produce it in the presence of environmental stress.

These features invalidate the complaints of Intelligent Designers that evolution cannot occur because mutation rates are to low and to rarely involve beneficial mutations to allow evolution to occur.

Proof of the role of STRPs in evolution. Given how enthusiastic I was about the explanatory role of STRPs for molecular evolution, I was especially excited by the subsequent studies of Fondon and Garner on the role of STRPs in evolution.[14] They took Darwin's lead that the variations in body form seen in domesticated animals over a short time span probably represents the same genetic process that occurs in evolution in nature, over much longer periods of time. Variants are incipient species. Since dogs are readily available, Fendon and Garner chose them to study the role of STRPs in the morphological variations seen in different breeds. They obtained DNA samples from 92 different breeds of dogs. Three-dimensional scans were made of the skulls of these dogs obtained from different museums. This allowed a total of 2.2 million individual measurements. They examined the STRPs associated with developmental genes, especially those known or suspected of being involved in the development of the face. These consisted of 21 *HOX* genes and 16 *HOX*-like genes. Their results indicated that selection for specific alleles of STRPs associated with genes involved in the bone structure of dogs played a significant role in the changes in body form involved in the selective breeding of dogs.

STRPs are especially associated with developmental and nervous system genes. Some STRPs consist of repeats of three bases (trinucleotide repeats) inside the coding regions of genes. Since the genetic code consists of three bases three trinucleotide repeats result in the presence of stretches of a specific amino acid in the protein gene product. These are called homopeptides (homo = same, peptides = small proteins). Two of the most common triplets are CTG and CAG, resulting in homopeptides consisting of leucine and glutamine respectively. These homopeptides may play a role in the regulation of the expression of genes.[15-17] These are all features that would also make this type of STRPs important in

evolution. The following paragraphs show a specific example of the role of homopeptides in evolution.

The Face of a Dog and Homopeptides of the RUNX2 Gene. In addition to their remarkable findings about the important role of microsatellite STRPs in evolution, Fondon and Garner [14] also reported a role of STRPs due to a homopeptide polymorphism. *The RUNX2 gene codes for a master regulator of bone formation.* In addition the *RUNX2* gene contains two trinucleotide repeats for homopeptides, one consisting of alanine and the other of glutamine. The polyAlanine represses transcription of *RUNX2* while polyGlutamine stimulates it. In the dog gene there are 18 to 20 glutamines followed by 12 to 17 alanines. *Different ratios of the number of repeats in these two sections play a role in different levels of activity of the RUNX2 gene.* Fondon and Garner hypothesized that various aspects of the shape of a dog's head may be related to different polyGlutamine to polyAlanine ratios. They sequenced this region in 124 purebred dogs from 90 breeds, calculated these ratios, and correlated this with the slope of the snout. The results are shown in Figure 5.

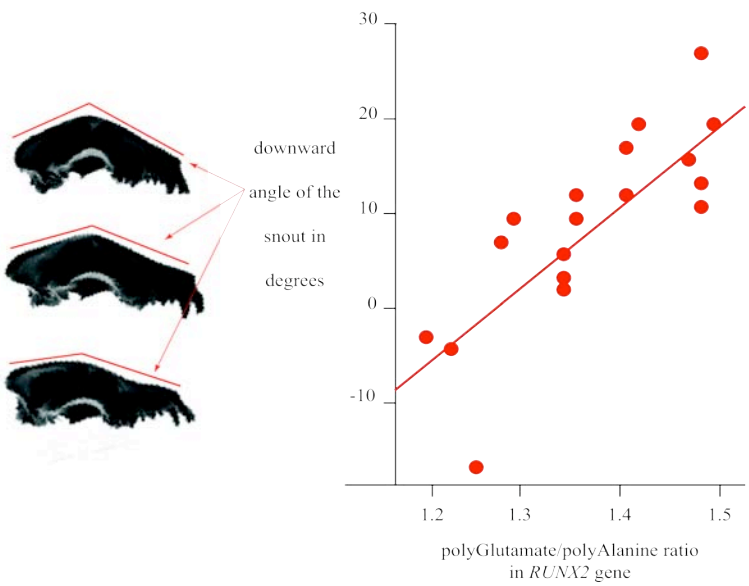


Figure 5. The relationship between the ratio of polyGlutamine to polyAlanine in RUNX2 and the angle of the snout in 90 different breeds of dog. Adapted from Fondon and Garner. PNAS. 101:18058-18063. [14] *By permission. National Academy of Sciences, USA. Copyright 2004.*

The greater the G/A ratio, the greater the angle of the snout. The correlation between the G/A and the angle of the snout was very high and significant (r^2 = .51, p = .0001, the r^2 value reflects the relative influence of the gene on the angle of the snout). 0 = no influence. 1 = 100 percent influence). There was also a high correlation with the midface length (r^2 = .63). This was another example of the important role of highly mutable, highly variable STRPs in the evolution of body form.

Darwin's Finches and Rapid Evolution

In Chapter 16, I describe the work of Peter and Rosemary Grant studying natural selection and evolution among the finches on the Galapagos Islands, made famous by Darwin. These studies showed that contrary to Darwin's thought that evolution proceeds very slowly over thousands of generations and millions of years, when major stresses such as droughts or floods occur, evolution proceeds very rapidly over one to a few generations and one to a few years. The reason it appeared to progress so slowly was that the changes produced by a drought and those produced by an excess of rain were in opposite directions. The end result was that over many years of alternating drought and flood seasons there was a false appearance of no change at all. However, if climatic or other environmental changes were to persist in a single direction, such as all drought or flood, evolution could occur very rapidly. It is likely that the genetic mechanism involves STRPs as described above.

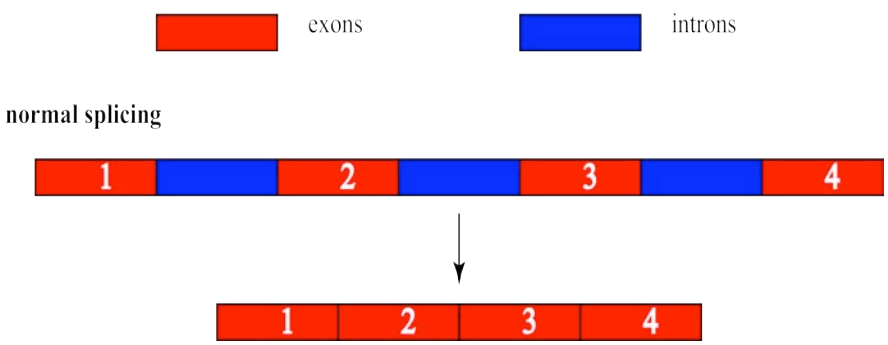
The studies of Fondon and Garner have shown that the role of STRPs in evolution is more than theoretical. They showed that the inheritance of different STRPs in a range of homeotic genes were involved in the changes in body morphology brought about by the domestication and inbreeding of 90 different breeds of dog.

Studies of finches on the islands of the Galapagos have shown that natural selection and evolution can occur with great rapidity, over only a few years and generations. It is likely that changes of this degree of rapidity also take place by the selection of pre-existing STRP alleles.

The Role of Gene Splicing in Evolution

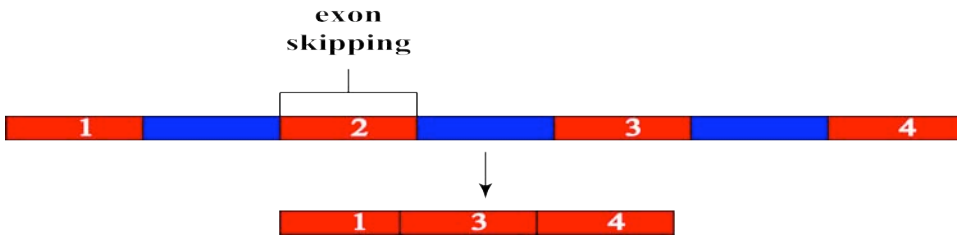
Eukaryote genes are divided into exons that actually code for proteins and introns that do not code for proteins. Both the exons and introns are transcribed into a large piece of RNA that remains in the nucleus and is called heterogeneous nuclear RNA (hnRNA). The RNA corresponding to the introns is spliced out of the hnRNA to produce messenger RNA (mRNA). The mRNA passes through the nuclear pores of the nuclear membrane, into the cytoplasm where it is read by the ribosomes to produce a specific sequence of amino acids resulting in a protein product.

Normal splicing is as follows:



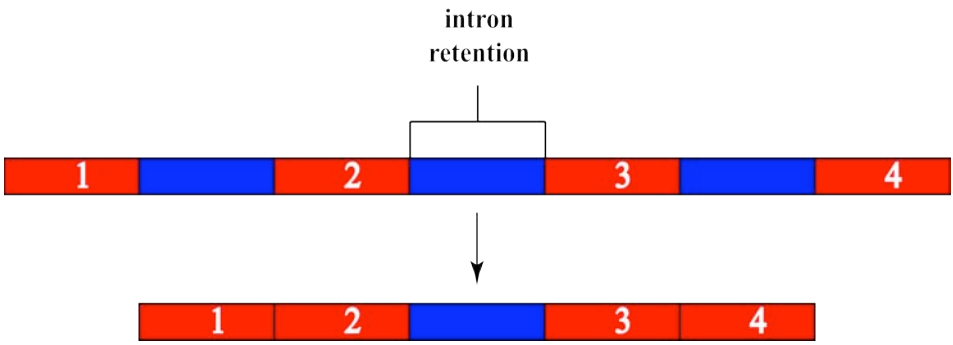
In humans the average gene is 28,000 nucleotides in length and contains an average of nine exons and eight introns. The exons average 120 nucleotides, while the introns can range from 100 to 100,000 nucleotides in length. Over 15 percent of gene mutations that cause disease act by causing alternative splicing. [18]

Exon skipping. One or more of the exons may be skipped during the splicing process.



Exon skipping is the most common form of alternative splicing in mammals.

Intron retention. The splicing may fail to exclude an intron, resulting in intron retention.



This is probably the earliest type of alternative splicing to have evolved. [19]

Splicing seems like a lot of trouble. What possible advantage is it? It allows the shuffling of exons to easily make new genes without having to start from scratch. A second advantage is that in humans, for example, it allows 90,000 different proteins to be made from only 25,000 genes. In other words, by alternative splicing, each gene on average can make three or more different proteins. A third advantage is that it may allow evolution to evolve different species from the same basic set of genes. Thus, one quarter of the alternatively spliced exons in both species are specific to either humans or mice. [20]

Alu generation of new exons. One group of alternatively spliced exons is unique to primates and may have contributed to the divergence of primates from other species. The primate-specific exons are derived from a mobile genetic element called *alu*, which belongs to a larger class of elements known as retrotransposons. These are short sequences of DNA whose function seems to be to generate copies of themselves and then reinsert those copies back into the genome at random positions, rather like little genome parasites. Retrotransposons are found in almost

all organisms and they have had a profound influence by contributing to the genomic expansion that accompanied the evolution of multicellular organisms. Almost half the human genome is made of transposable elements with *alu* sequences being the most abundant. [18]

The *alus* were long considered nothing more than genomic garbage, but they began to get a little respect as geneticists realized how *alu* insertion can expand a gene's protein-generating capacity. All it takes to convert some silent intronic *alu* elements into real exons is a single-letter change in their DNA sequence. [18] At present, the human genome contains approximately 500,000 *alu* elements located within introns, and 25,000 of these could become new exons by undergoing this single-point mutation. Thus, *alu* sequences have the potential to continue to greatly enrich the stock of meaningful genetic information available for producing new human proteins. Evolution works by presenting organisms with new options, then select and keep those that confer an advantage. Novel proteins created by the splicing in of new *alu*-derived exons probably helped to make humans the species they are today.

Alternative exon splicing adds a new capability to the evolutionary toolbox. In previous sections I discussed the great power of gene duplication to allow rapid evolutionary changes without having to make new genes from scratch. Exon splicing is in essence an alternative to gene duplication, but without the necessity of making a new gene. It allows the same gene to produce several different proteins, one of which retains the function of the original protein. Splicing may have become so prominent because of this powerful capability. It allows humans to have the diversity and capabilities of a 90,000 gene organism, while in reality having only 25,000 genes.

A role of STRPs in exon splicing. We saw in the first part of this chapter the powerful role that STRPs have in evolution. Lian and Garner [20] have now suggested that STRPs may also play an important role in alternative exon splicing. They found that while less than half of the proteins in the Human Alternative Splicing Database are known to be alternatively spliced, 84 percent of those that are alternatively spliced contain STRs. These complementary repeats could play a role in the regulation of alternative splicing. Since these sequences are known to have a high mutation rate this would contribute an additional method for rapid change during evolution.

During evolution alternative exon splicing provides a powerful mechanism for rapid changes in the way the genome expresses itself, yet requires few changes in the DNA sequence. For example, it allows humans to have the flexibility and diversity of 90,000 genes while possessing only 25,000 genes.

Other Mechanisms of Rapid Genetic Change

In addition to the above there are a number of other mechanisms by which the DNA sequence of the genome can change much more rapidly than by single base pair mutations. Some of these have already been discussed and are included here to make a complete list. All of these mechanisms utilize the principle of reusing previous

solutions, previously developed modules, previously developed genes, or parts of genes. I have listed these in approximate order of the size of the reused module.

Endosymbosis. This has been discussed previously. It involves the reutilization of very large modules—chloroplasts and mitochondria—from bacteria.[21] This relieved newly evolved eukaryotes of the need of developing from scratch a mechanism for producing energy from light or sugar, a fundamental requirement for life.

Whole Genome Duplication. In 1970 Susumu Ohno suggested that during the course of vertebrate evolution, the entire genome was duplicated twice.[22,23] This doubling of the number of chromosomes is called *polyploidy.* It is especially common in plants and can rapidly lead to the evolution of new species.[24,25]

Gene duplication. Gene duplication is one of the most widely used mechanisms to make new genes by producing two copies of old genes, keeping one for the original function and allowing the other to diverge to take on new functions.

Hybridization. Hybridization occurs when two different but closely related species mate and produce fertile offspring. While the definition of a species usually implies two groups that do not mate in nature and would not produce fertile offspring if they did, the definition is not violated if the offspring are occasionally fertile. Certain environmental conditions may increase the probability of this occurring. The outcome is a wider range of alleles at the genes of each, and this may improve natural selection for more fit organisms and accelerate new speciation.[26,27]

Gene Displacement/Gene Opportunism/Cooption. Gene opportunism occurs when the protein product of a given gene has multiple functions. Each function is often in a specific place. Thus, one function may be inside the cell while the other function is outside on the cell surface. The difference can also be in different cell types. Proteins with these different functions have been referred to as moonlighting proteins.[28] This is a characteristic of many proteins.[29] The following are two striking examples.

First, one function of phosphoglucose isomerase is to catalyze the interconversion of glucose 6-phosphate and fructose 6-phosphate. However, other moonlighting functions include being a neuroleukin, which is both a nerve growth factor and an agent for maturing lymphocyte B cells; being an autocrine motility factor that stimulates cell migration; and being a factor that can cause the differentiation of human myeloid leukemia cells. A second example is the lens protein of the eye called *crystallin.* It also functions as heat shock protein, a stress response protein, and has seven different enzyme functions.

Gene displacement, or *opportunism,* or *polygeny* is a powerful mechanism in evolution. When speciation requires the development of a specific function, it is often possible to call upon the services of a protein whose gene is already present. Instead of inventing a new gene the only thing required could be a single mutation in a promoter or other gene region that *allows the gene to be expressed in a new organ or new place in the cell.* A related process is called *pleiotrophy.* This refers to the situation in which a single gene can be expressed as several different physical effects or traits or phenotypes.

This general phenomena has also been called *cooption.* Cooption is basically a shift in function in which a given system or gene product that had function A can subsequently be co-opted to have a different function B. This is especially easy to do if the gene was first duplicated so the original function A is not lost while the duplicated gene is coopted. Cooption was first proposed as a tool in evolution by Darwin.

Chromosome Rearrangement. Chromosomes contain hundreds to thousands of different genes. Many varieties and species, especially in plants, arise following various types of chromosome rearrangement. [30p603]

Horizontal Gene Transfer. As discussed previously horizontal gene transfer between species was so prevalent in prokaryotic organisms that it was not until the development of eukaryotes with a nuclear membrane that this process was slowed enough to allow for the evolution of more complex species. However, for prokaryotes, this process allows species to acquire new genes without the necessity of starting from scratch.

Jumping Genes. In 1948 Barbara McClintock began to report her studies in corn suggesting that genes could jump around in the genome. [31] These jumping units were called *transposons.* This was so bizarre to the scientific establishment that her work was ignored for years. However, over time the fact that her ideas were correct began to be accepted, and in 1983 she received the Nobel Prize for this innovative and groundbreaking work. Like the other mechanisms on this list, the presence of transposons allows the *rapid rearrangements of genetic material*. When beneficial the prevalence of the new arrangement in the population would be increased by natural selection.

Sexual Recombination. In asexual reproduction all of the genes of the parent, including new mutations, are passed to each offspring. Sexual reproduction involves the formation of an egg and a sperm, each of which have only half of the parent's genes. When a sperm fertilizes an egg, the full complement of genes is restored, half from the mother, half from the father. From the point of view of a strong parent wanting to pass his or her genes to their offspring, this is inefficient since only one half of the strong parent's genes are passed on. What advantage compensates for this inefficiency?

In addition to acquiring new genes, it is sometimes just as important in evolution to acquire specific combinations of genes. This is uniquely possible with sexual recombination. This form of reproduction started in the pre-Cambrian period and helped to accelerate evolution.

***Alu* sequences.** The important role of *alu* sequences was discussed above. However, there is part of this story that needs emphasis. *Alus* typically contain a poly A (adenine) sequence. Stretches of polyAdenine are added to the 3' end of messenger RNA after splicing. Thus, any sequence with polyAdenine is likely to have been derived from messenger RNA, the transcript that contains the essence of different genes. The ability to disperse such sequences throughout the genome to form new exons would provide a method of rapidly inserting sequences with proven functions into new genes.

Exon Shuffling and Domain Exchange. Proteins consist of multiple different domains each with a different function. Some proteins contain over a dozen such

domains. These different domains are carried in different exons. As described previously, one of the major advantages of dividing genes into exons and introns is that exchanging exons, often called exon shuffling or domain exchange, allows the sharing of the same successful domains by many different genes. [32]

Repetitious peptides. The smallest modules that can be reused are short stretches of protein or peptides that have been used many times in many different genes in evolution. For example, albumin and alpha-fetoprotein contain tandem repeats of an 18-nucleotide-long primordial building block coding for a six-amino-acid peptide, and this contains smaller blocks of five and six nucleotides. [33] Many other proteins including collagen, β_2-microglobulin, different neurotransmitter receptors, and probably all genes, are also made up of similar repeats of short peptides. [34,35]

Creationists and the Intelligent Designers repeatedly claim that the production of beneficial variants by single nucleotide mutations (STMs) is too rare and too slow to allow for evolution. This ignores the fact that much evolution is not the result of this type of rare genetic change. DNA composed of repetitious sequences in the form of short tandem repeats (STRs) mutate a million to 10 million times faster than STMs and play an important role in gene regulation and evolution. In addition to this mechanism, reusing or exchanging pieces of DNA that have already proven themselves in other situations accomplishes most evolution. The processes for rapid evolution include:

- **Endosymbiosis**
- **Whole genome duplication (polyploidy)**
- **Chromosomal rearrangements**
- **Gene duplication**
- **Hybridization**
- **Gene displacement**
- **Horizontal gene transfer**
- **Jumping genes**
- **Sexual recombination**
- **Retrotransposons (Alu sequences)**
- **Exon shuffling and domain exchange**
- **Repetitious DNA and repetitious peptides**

These processes allow whole genomes, whole chromosomes, parts of chromosomes, whole organelles (chloroplasts and mitochondria), whole genes, specific combinations of genes, whole gene domains, and parts of gene domains to be put to new uses—over and over again. This reuse of what already works allows for the rapid acceleration of evolution and speciation and allows for a rapid response to environmental change and geographical isolation. As a result—there is plenty of time for evolution to occur.

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The only incomprehensible thing about the universe is that it is comprehensible. Why can we figure it out so well?

Albert Einstein

Chapter 7

Complexity—Introduction

In 1691 John Ray published a book entitled *The Wisdom of God Manifested in the Works of the Creator.* In it he gave many examples where organisms or organs were so complex they must have been the work of a supernatural creator. In a similar vein, in 1802 William Paley [1] wrote that if it took a highly trained watchmaker to make a watch, then it must have taken a supernatural power to construct things as complex as those seen in the living world of biology. This famous statement led Richard Dawkins to entitle his book, *The Blind Watchmaker,* [2] explaining how evolution by random variation and natural selection could accomplish these biological wonders.

In his book, *Darwin's Black Box,* [3] Michael Behe claimed that not only have evolutionists not provided an explanation for some complex structures, he claimed they never would be able to provide such an explanation because some structures are "irreducibly complex."

> By irreducibly complex I mean a single system composed of several well-matched, interacting parts that contribute to the basic function, wherein the removal of any one of the parts causes the system to effectively cease functioning. [3p39]

To make sure he had made his point he further elaborated on this theme:

> An irreducibly complex system cannot be produced directly by numerous, successive, slight modifications of a precursor system, because any precursor to an irreducibly complex system that is missing a part is by definition nonfunctional. Since natural selection can only choose systems that are already working, then if a biological system cannot be produced gradually it would have to arise as an integrated unit, in one fell swoop, for natural selection to have anything to act on. [3]

Then in a modest, self-effacing evaluation of his own work he stated,

> The results of these cumulative efforts to investigate the cell—to investigate life at the molecular level—is a loud, clear, piercing cry of "design!" The result is so unambiguous and so significant that it must be

> ranked as one of the greatest achievements in the history of science. The discovery rivals those of Newton and Einstein, Lavoisier and Schrödinger, Pasteur, and Darwin. [3p232]

At a minimum, his work helps us to understand why standard scientific findings presented in academic journals are subjected to impartial, independent review prior to publication. The evaluation of their worth cannot be left up to the authors themselves.

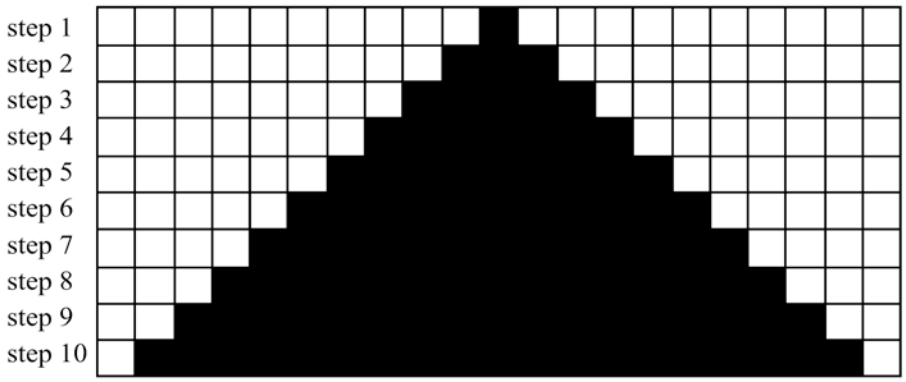
Many of the creationists' and Intelligent Designers' complaints against evolution involve what is termed *argument from ignorance.* This approach involves concluding that if the evidence for something is not currently available it never will be. We saw above that this failed when they claimed that since some of the important intermediate or transitional forms in evolution had not been found, they never would be found. In fact, they were quickly found. Behe uses the same faulty reasoning. If some mechanism about the evolution of a complex system is not known, it never will be known. In the following pages and chapters I examine and hopefully counter these claims. This introductory chapter presents some theoretical aspects of the complexity issue. In subsequent chapters I will directly address some of the Intelligent Designers' specific concerns.

Complexity and Cellular Automata

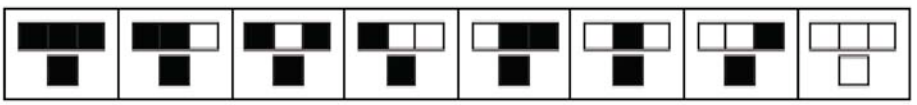
Stephen Wolfram, the author of the equation-solving computer program known as *Mathematica,* [4] published a book entitled *A New Kind of Science.* [5] His theme was that a wide range of very complex forms can be produced by a small number of initial rules. Because the program had a graphic format consisting of black or white cells, he used the term *cellular automata.* For example, we can take a piece of graph paper and blacken in one square.

One simple rule is that on the next row, any grid square that is either immediately below or below and adjacent to the original square is also blackened in.

When this process is continued many times, the following pattern develops.

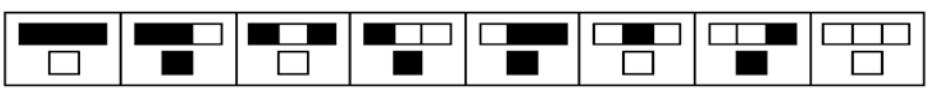


A set of eight simple sub-rules for this can be diagrammed as follows:



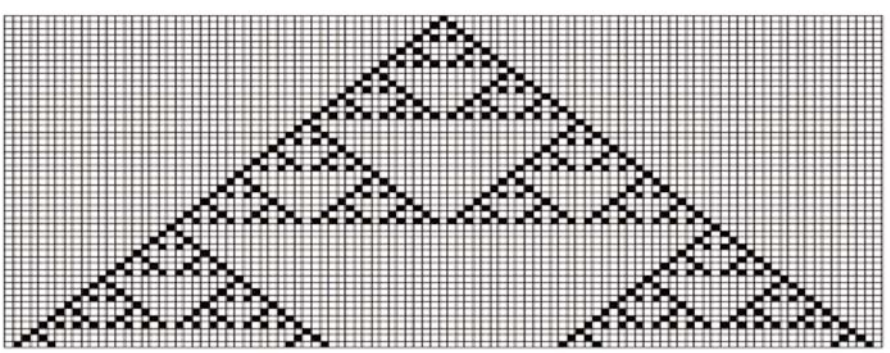
1 2 3 4 5 6 7 8

The top row shows the blackened squares already produced. The bottom row shows whether the square in the middle of the next row will be black or white. Boxes 1 to 8 show the rules when the eight different possible combinations of the top three cells are black or white. Since there are only two colors, black or white and eight possibilities, there are 28 or 256 possible sets of these rules. This was rule 254. Minor alterations in the rules can change the output from the above simple pattern to very complex patterns. For example, rule 90 is:

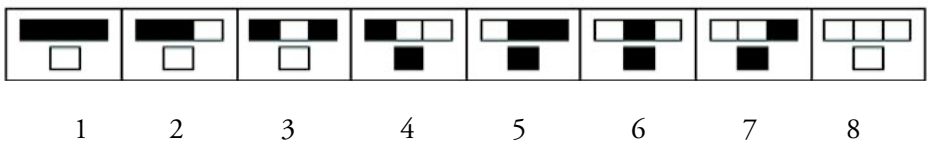


1 2 3 4 5 6 7 8

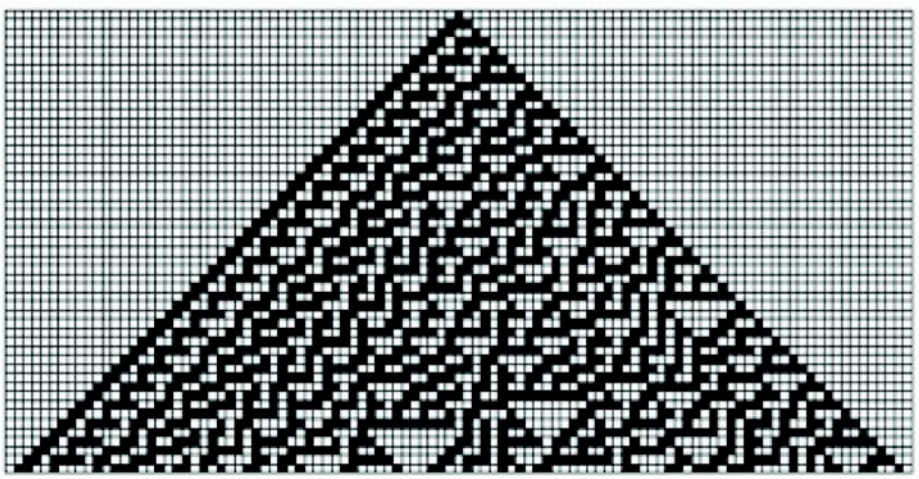
It differs from rule 254 in that for sub rules 1, 3, and 6 the bottom square is white instead of black. This now produces the following complex pattern:



A further example is rule 30.



This differs from rule 90 in that for sub-rule 2 the next square is white instead of black and for sub-rule 6 the next square is white instead of black. This produces the following pattern:



The important implication is that *very complex patterns can result from very simple starting rules.* While the reader may be skeptical about what relevance this has to the issue of whether Darwinian evolution and natural selection can produce very complex structures, I show in the following sections that it is remarkably relevant. The next section reviews studies of a computer program that was specifically designed to model evolution by genetic variation and natural selection. This simple program also produces very complex outcomes. Previously I reviewed the new field of evolutionary development dubbed "evo devo," which shows that a small set of body shape genes termed the developmental "toolbox" can account for the evolution of the enormous diversity of animal forms. Thus, some of the philosophical implications of cellular automata are relevant.

Theism and The Principle of Computational Equivalence. In addition to the above statement that very complex outcomes can result from simple starting rules, Wolfram examined the converse of this and found that if he attempted to produce even more complex patterns by using a set of even more complex rules, the result was a simpler rather than a more-complex outcome. The implications of this are quite profound, so much so that Wolfram elevated this observation to a grand concept he called the *Principle of Computational Equivalence*. He states, "In essence, the *Principal of*

Computational Equivalence introduces a new law of nature to the effect that no system can ever carry out explicit computations that are more sophisticated than those carried out by systems like cellular automata." [5p720] In other words, *no matter how complex the outcome, it is still likely to have been the result of a few simple rules.*

As discussed later, this concept certainly has validity for the string theory of the cosmos. Many religions, including Christianity, and the entire Intelligent Design movement, propose that the complexity of nature is so great that it can only be explained by the workings of a supernatural power. The *Principle of Computational Equivalence* suggests the opposite, that once a given level of complexity is attained, a level that is easily explained by a set of simple rules, a further increase in the level of complexity cannot be produced by evoking causative factors of still greater complexity. Since the concept of God is the most complex causative or creative factor ever proposed, the *Principle of Computational Equivalence* suggests evoking a God to explain complexity—is not necessary.

Very complex outcomes can result from simple starting rules.

Artificially increasing the complexity of the starting rules leads to simpler rather than more-complex outcomes.

This leads to the *Principle of Computational Equivalence,* which states that no system can ever carry out computations that are more sophisticated than those carried out by simple systems like cellular automata. This has the profound implication that it is not necessary to evoke the complex concept of God to explain the development of seemingly very complex organs or organisms.

Computer Models of Evolution—Avida

Wolfram's cellular automata program demonstrated that great complexity can derive from a set of simple rules and that attempting to increase the complexity of the rules led to lower rather than greater levels of complexity. Natural selection of the results was not a part of the program. What happens when selection is a part of the program?

Christoph Adami and colleagues in the Digital Life Laboratory at California Institute of Technology in Pasadena and Richard Lenski and colleagues at Michigan State University in East Lansing developed a sophisticated program of this type called Avida. [6,7] Lenski had previously worked on evolution in bacteria but found the information provided by Avida to be so much more powerful that he switched to studying evolution in the digital world. Over a period of many years of work on bacteria, Lenski observed features that supported the concept of *punctuated equilibria.* Over 35,000 generations of bacteria evolved that were larger and grew faster. These changes were not smooth and linear but showed periods of rapid change alternating with periods of little change.

The advantage of computer-based evolution is that the time from one generation to the next is many thousands of times faster than for bacteria and many hundreds of thousands of times faster than for humans. In Avida all of the facets of Darwinian

evolution are in place—replication, mutation, and natural selection. Instead of being restricted to examining evolution over 35,000 generations requiring years of experimentation, in the digital world evolution can be followed over millions of generations in minutes. The number of generations involved simulates the passage of geologic time.

Living animal organisms do things like respiration where they take in oxygen and put out carbon dioxide, and digestion where they consume food such as sugar and put out usable packets of energy in the form of ATP (adenosine triphosphate). What do digital organisms do? They work with food in the form of being fed numbers. One of the things that computer programs do is compare numbers. This is done by a fairly complex operation known as "equals" and involves a bit-by-bit comparison. The shortest program that can do the equals function requires 19 lines of computer code.

The chance that simple random events could produce this complex 19-step program is about 1 in a thousand trillion trillion. [7] What happens when random events are coupled with selection? In the digital world selection is represented by rewards for modest improvements on simple code and larger rewards for more complex code. Rewards take the form of supplying the program with more numbers (food).

As with living organisms, most of the mutations are either neutral with no effect, or deleterious and make things worse. Only a few mutations are beneficial. One experiment was set up so the organisms would replicate 16,000 times. This was repeated 50 times. Did selection improve the odds of producing a functioning equals program? Yes, dramatically, in that 23 of the 50 experiments produced a functional equals program, not the trillions of trials expected without selection. This illustrates the incredible power that can be obtained when random mutation is coupled with selection, even when beneficial mutations are rare.

When the rewards, i.e., selection, were taken away, none of the trials produced an equals program. Even more remarkable all 23 of the equals programs that were produced with rewards evolved in a different way. This is also consistent with a dictum of evolution—*the random process can come up with many different solutions for the same end product.*

These digital organisms also provide insight into another aspect of evolution. Ecologists have found that up to a certain point, the more energy or food provided by a given ecological niche, the more different types of organisms evolved. However, if too much energy (food) is supplied the number of organisms was more limited. The digital organisms showed the same phenomena. When plenty of energy (numbers) was supplied, only a single predominant program evolved. However, when the numbers were limited, multiple different programs evolved, each specialized for a different sub-function. Even more surprising, on a restricted diet of numbers the frequency of successful programs increased to 50 out of 50 trials and the equals programs evolved five times more rapidly. This represents the simple fact that the more stressful the environment (restricted diet) the more rapid the rate of evolution.

The Intelligent Designers have repeatedly pointed out that some complex multi-step or multi-component biological processes do not work if even one of the

steps or components is left out. They argue that the probability of getting all steps working together by the process of random mutations and selection is so remote that Intelligent Design by a superior power must have been involved. As with these complex biological systems, the equals program also required multiple steps and if any one was left out the program did not work. Despite this, when exposed to a limited input of numbers, the equals programs evolved quickly and at a high probability (50 out of 50 times). This shows that *when random mutations and selection are combined irreducibly complex organisms can evolve rapidly and efficiently.*

Computer Models of Evolution—EV

Schneider[8] described another computer modeling of evolution. The programs were called *ev, ecd* and *lister.* A small population of 64 "organisms" was created; each genome consisted of 256 random bases, A, T, G or C. The organisms contained a target sequence of DNA to be recognized and the goal was to evolve a section of the genome that coded for a protein that recognized and bound to the target DNA sequence in a different part of the genome.

The organisms were subjected to rounds of selection and mutation. Mistakes were made in either failing to recognize the target DNA sequence or binding to a non-target DNA sequence. The number of mistakes made by each organism was determined. The "natural selection" component consisted of allowing only the half of the population with the fewest mistakes to reproduce by having them replace the other half that made more mistakes.

At every generation each organism was subjected to one random point mutation. At the start the organisms contained a random DNA sequence in which the information content of the binding sites was essentially zero. The results are shown in Figure 1.

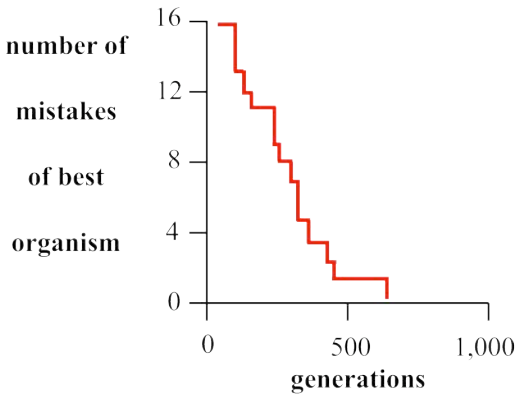


Figure 1. Number of mistakes for best organism in successive generations. From Schneider: Evolution of Biological Information, Nucleic Acids Research. *28:2794-2799, 2000. By permission.*

Remarkably, the cyclic mutation and selection process led to a mistake-free "organism" in only 704 generations. When "natural selection" was removed the information content of the recognition sequence rapidly decayed. This study showed how the information gain came about from mutation and selection, without the "outside influence" proposed by the creationists and Intelligent Designers.

The *ev* program also has relevance to the claims by Behe[3] of "irreducible complexity." The recognizer section and its binding site co-evolved in the *ev* program. They were interdependent upon each other, and destructive mutations in either immediately led to elimination of the organism. In this respect it was similar to the proposed irreducible complexity consisting of such interacting parts of a structure that the removal of one led to loss of function of the whole. However, *in ev, despite the interdependence of the two parts, the molecular evolution of the whole was straight-forward and rapid, in direct contradiction of Behe's thesis.*

In the *ev* program, the probability of finding 16 sites (recognition sites) averaging 4 bits each in random sequence was 5×10^{-20} (5 chances in one hundred billion billion). Despite this, the sites evolved from random sequences in less than 800 generations. This dramatic effect of combining natural selection with random mutation is similar to that observed in the Avida program.

Computer modeling of evolution using digital organisms shows that the combination of random mutations with natural selection is incredibly powerful and efficient. In one program the probability of a 19 component program evolving on the basis of random mutations alone was one in a thousand trillion trillion. When selection was added in combination with a "stressful environment," the probability increased to 1 in 1.

In a second program the probability of finding a 16-site component was five in one hundred billion billion generations. When selection was added the component evolved in 704 generations, a thousand billion times faster.

With this powerful combination of mutation and selection, irreducibly complex processes or organisms can evolve rapidly and efficiently.

The Real Thing

While these computer models might be called simulations, they are not simulations but the real thing.[9] They do not simulate evolution; evolution is actually occurring. This is demonstrated by the fact that these studies have led to a new field of research called *evolutionary computation.* This involves using random changes in a computer program plus selection to design a wide range of practical things including airplane wings, manufacturing schedules, natural-gas transport pipeline networks, robots, and others.[9p105] In many cases the results are more creative and innovative than the efforts of very talented engineers and industrial designers. The power of this

method is that a large number of random variations are tested. Those that work form the starting point for further changes. Those that fail are discarded. Evolutionary computational design is so effective that Boeing used the technique to design the geometry of the engine of the Boeing 777. [9p105]

Monkeys and Typewriters

One of the statements often made by those who advance the concept of Intelligent Design is to suggest that it is just as impossible for random mutations to result in the evolution of complex structures as it is for a series of monkeys randomly pounding on a typewriter to write poetry or literature. This complaint indicates a lack of understanding of how powerful the combination of random mutations, small steps, cumulative changes, and natural selection can be.

Let us suppose we had one thousand monkeys randomly typing on a typewriter and that they hit one key each second. Based on the keyboard I am currently using, there are approximately 28 letter or space keys. Thus, we will have the monkeys use a 28-key typewriter. Then let us take small steps in the form of groups of 10 letters or spaces. Natural selection will be in the form of a hypothetical English teacher who decides whether the words produced make sense and have the potential to tell a story (survival value). The following are some results that our form of natural selection might allow to "survive."

There was…
Once upon…
Alice was…
David was…

Without spending a lot of time trying to determine the exact number of selectable 10-letter outcomes, let us simply say there are 1,000 combinations of 10 letters and spaces that could be given the stamp of survival by our hypothetical English teacher. The chance that any one of these possibilities would occur after the monkeys were typing for one hundred years is 1/2810 x 1000 (possible outcomes) x 1,000 (number of monkeys) x 60 (seconds per minute) x 60 (minutes per hour) x 24 (hours per day) x 365 (days per year) x 100 (number of years) = 10. Thus, in only 100 years there would be 10 suitable outcomes that survived our form of natural selection. The final requirement is that once a suitable outcome had been selected, the process would start over to build on the 10 acceptable outcomes. Here the English teacher providing natural selection would have to select the new subsequent outcomes that were consistent with what had already evolved. It is reasonable that this requirement would cut in half the number of suitable outcomes, now requiring 200 instead of 100 years. Thus, if we take the first outcome listed above, the following are some possible second stage outcomes.

There was…an old man

There was…a nice boy
There was…a bad girl

For subsequent rounds we could assume there would be even more restrictions on the number of suitable outcomes, as the form of the story began to take shape. However, the evolution of the final story can actually be rapidly accelerated by using previously completed modules, in this case words. As with evolution, it is not necessary to re-invent the wheel; once a word has evolved the whole word can be randomly used in subsequent "organisms." Eventually, a number of meaningful different stories would have evolved. This simple concept has a number of lessons and analogies relevant to real evolution.

1. Small steps. It is a common tactic of proponents of Intelligent Design to suggest that some things are too complex to be the result of random genetic change and natural selection. They invariably talk as though everything happened in one step. However, when taken in small cumulative steps, with natural selection at each step, quite complex organisms and structures, or in this case stories, can be produced.

2. Cumulative changes. The power of small steps is greatly multiplied by adding together the successive improvements, in this case, improvements in the unfolding story.

3. Non-directive. It has been repeatedly pointed out that Darwinian evolution is non-directive. That is, there is no predestined goal. It is truly blind. [2] The end result is simply what has survived the selection process. When we use *Homo sapiens* as an example of the outcome, our egos tend to lead some of us to believe we are the best possible outcome, and therefore a superior force directed the process. However, as in the many different stories in the above examples, biological evolution also has many different potential outcomes, as abundantly illustrated by the wide diversity of species on earth. Humans could have evolved to have four eyes instead of two, and three pairs of extremities instead of two, or even an average IQ of twice what it is currently. Had that been the outcome, we would probably view the thought of having only two eyes and two pairs of extremities as ugly, or inefficient, or both, and an average IQ of 100 as really stupid.

4. Multiple paths to the same goal. A similar but not identical concept is that an equally competent end result can be built from a number of different pathways. Here we may have had a similar outward appearance, but there may be more subtle differences in a number of metabolic pathways or internal organs producing multiple paths to a similar outcome. In the above analogy, the same story message could have been delivered using a wildly varying combination of words, sentences, and paragraphs, just as the concepts in these paragraphs could have been stated many different ways, and probably more elegantly, without losing the gist of the message.

5. Modularity. This refers to an interchangeability of parts. Thus, the above phrase, "There was an old man…" could be used as the beginning of many different stories without the need to evolve the phrase over and over. Internal to the story, the phrase, "He said," or "She said" could be used as a module over and over without needing to reinvent the phrase. Even single words would not have to be re-invented

and could be reused. As described previously once a gene, an exon, or a domain has evolved and proven its survivability in natural selection, there is no need to reinvent it. By exon or domain shuffling, or in this case word or phrase shuffling, successful solutions are used and reused to accelerate the rate of evolution.

As with the digital model of evolution, a very simple model of 1,000 monkeys randomly hitting the keys of a typewriter, with every meaningful set of 10 letters being selected, shows the enormous power that small steps and natural selection play in the evolution of complex structures. Without small steps and selection, the Intelligent Design theorists and creationists would be correct—the probabilities of obtaining a meaningful outcome in a single step are remote in the extreme. However, the simple addition of multiple small steps with natural selection at each step allows the evolution of very complex structures and organisms.

Basic Argument from Improbability

One of the favorite ploys of the Intelligent Design group is to argue that the probability of something occurring in a single step is so remote that a supernatural being must have performed it. This whole area has been referred to as the *Basic Argument from Improbability (BAI).* [10p126] The purpose is to "prove" that something cannot happen by displaying huge negative exponentials—then claiming that evolution or some aspect of biology is false because the mathematical probability of it occurring is so low that it is effectively impossible. For those uncomfortable with numbers and statistics, what does the term *huge negative exponentials* mean?

If 10 people are in a pool, betting on the outcome of a football game and only one person can win, the chance of winning is 1 in 10, or 1/10. Written in the decimal numbering system, this is 0.1. If there were a thousand people in the pool, the chance would be 1/1000 or .001. As the chances of winning get smaller, the number of zeros after the decimal point gets larger and soon it is difficult to keep track of them. Thus, the number can be written in its exponential form, in this case 10^{-3}. The $^{-3}$ indicates you have to count three positions in the minus direction (left) to find where to put the decimal point, i.e., .001. Thus, if we say the chance of X occurring is 10^{-10} this would represent .0000000001, or 1 in 10 billion, a very small chance.

As an example of BAI, in a book entitled *Scientific Creationism,* Morris [11] calculated that the chance of a given organism occurring in one step was 10^{-53} or one chance in a hundred million billion billion billion billion billion billion, or essentially no chance at all. The granddaddy of all BAIs is that of Hoyle and Wickramasinghe. [12] They estimated the chance that the amino acids would randomly line up to form the first hemoglobin molecule was 10^{-850}. This is a truly low probability since there are only 10^{80} atoms in the whole universe.

These statements make a number of fundamental mistakes. First, they assume the organism or structure in question was formed in a single step. The whole point of the

theory of evolution is that many thousands if not millions of steps were required over several billion years to get to the point of discussion.

In the case of hemoglobin, it also ignores the fact that as long as the amino acid histidine was present to bind heme, there were thousands of different amino acid sequences that could do the oxygen-carrying work of hemoglobin. They also ignore the power of natural selection. As illustrated in the discussion above on digital evolution, a one-step probability of 1 in a thousand trillion trillion, or 10^{-26}, was reduced to 1 in 1, or 10^{-0}, when selection was added.

A final mistake is that BAI is often an exercise in absurdity. For example, using the above reasoning let's assume that I wish to determine the chance that I am really sitting at my desk. Given the size of the universe, there are at least 10^{+53} places I could be instead. Thus, there is only a 10^{-53} chance I will be where I am. Since this is such a small number, I must not exist! This is reminiscent of the story of the man who returns home early and hears a noise in the bedroom. He opens the door just in time to see the closet door close. When he opens the closet door he finds a naked man standing there and asks,

"What are you doing in my closet?"

To which the man replies, "Everybody has to be somewhere."

I too have to be somewhere. Adding up all the places I could be does not affect the probability that I am where I am.

Quoting ridiculously low probabilities that a gene or organ or organism could arise by chance in a single step ignores three fundamental features:

- **The evolution of these items took place in millions of small steps over billions of years, not in a single step.**
- **Natural selection was also involved—an enormously powerful added factor.**
- **By not taking these fundamental elements of evolution into consideration—random variation plus selection—it is easy to misrepresent the probability of events.**

Modularity

The power of reusing modules ranging from whole genomes to mitochondria, chloroplasts, whole genes, domains, exons, and sub-exons is of such importance that it will be emphasized and reemphasized. The examples of so called "irreducible complexity" given by Behe and other Intelligent Designers can all be answered by the power of modules. The following is a simple example of the power of the use of modules originally designed for one purpose, for a new purpose.

Evolution of a car. It could be claimed that a car is an example of irreducible complexity. Since many of its parts are critical to the function of the car, losing any one would result in a car that did not work. Therefore a car cannot be the result of evolution because the probability of simultaneously evolving all functioning parts is essentially zero.

The fallacy of this line of reasoning lies in two assumptions.

1. The car could not work when some of its parts are missing. For the purposes of this discussion and to keep it simple, I will assume that the chassis, motor, wheels and battery are the proposed irreducible components. The Intelligent Designers often state that a given example cannot function when one of its parts is removed. This is frequently not true. In the car example, a car without a motor or a battery is a cart—in use for centuries to carry goods. The motors only made it easier.

2. None of the parts had a function independent of the car. In my example, the chassis, wheels, motor, and battery also had other purposes before the car was invented. Figure 2 illustrates how a complex structure like the automobile is both reducible in that parts can be removed and still leave some functionality and modular in that the different component parts have other functions independent of the function they carried out in the automobile. This simple example illustrates three important points.

- The cases proposed by Behe and other Intelligent Designers are often reducible (not irreducible), since they can function at a more primitive level without needing every component.
- All the components do not have to evolve simultaneously—parts or modules often served other functions before they were incorporated into a more complex structure.
- A final important point is that the final structure may simply show what might be best called *pseudo-irreducibility*. The automobile serves as an example. If any of the four above components are removed the automobile does not work as an automobile. If we take out the engine, for example, it can no longer function as an automobile but it can function very well as a cart to transport things. In subsequent chapters I will further illustrate this concept.

Cases of so-called "irreducible complexity" are often not irreducible. In addition, the complex organ is often modular in that it is composed of modules that had a different use before being incorporated into the more complex function. This eliminates the necessity for all parts to evolve simultaneously.

In the following chapters I address some of the specific claims of irreducible complexity proposed by the Intelligent Designers and illustrate some of these points. For each claim I will ask two questions—It is really irreducible? Is it modular? The two questions are closely related; if the parts are modular, the system is reducible.

It is not my purpose to provide detailed answers to every complaint of the Intelligent Design creationists. My purpose is to show that when all the available information about these systems is examined, they are all both reducible and modular. For one of these systems, the immune system, I refer the interested reader to articles on the web by Inley [13] since it would have taken a very dedicated lay reader to ascend the learning curve necessary to follow the reasons why all the aspects of the immune system claimed by Behe [4] to be irreducibly complex are actually reducible and modular.

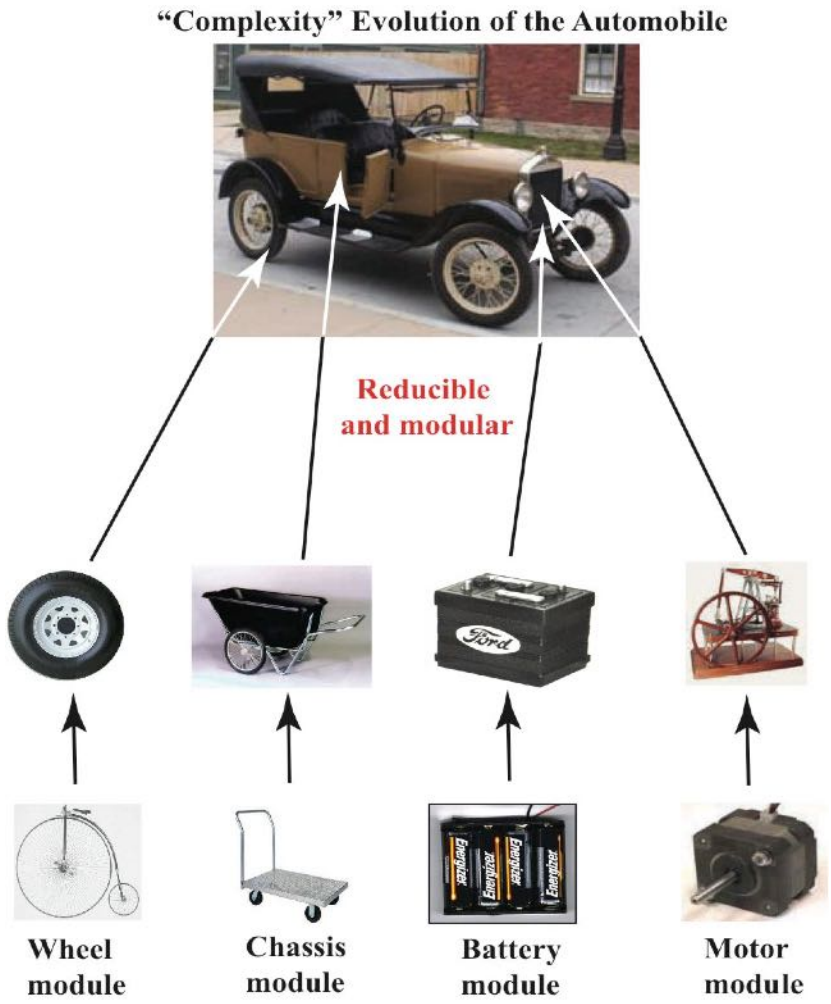


Figure 2. Reducibility and modularity of a complex structure, the automobile.

For several of the following chapters I thank the many other authors who have led the way in responding to Intelligent Design claims that some systems are irreducibly complex and can only be explained by Intelligent Design.[2,14-18] Two excellent web sites devoted to answering Intelligent Design are www.talkorigins.org and www.talkdesign.org.

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Chapter 8

Complexity—Eyes

Being able to see where you are going, where your food is, and where your enemies are has such a powerful advantage for animal survival that it is little wonder that over 40 different independent solutions for serviceable image-forming eyes have evolved with at least nine different design principles. These include pinhole eyes (like ours), curved reflectors, and multiple types of compound eyes. [1] I have started these chapters on complexity with eyes because Darwin also discussed eyes as an example of how complex structures could have evolved. The following are some of the things Darwin said about the evolution of eyes:

> Numerous gradations from a simple and imperfect eye to one complex and perfect can be shown to exist, each grade being useful to its possessor.

Darwin viewed such evolution as occurring in multiple steps. One was connecting a nerve to light-sensitive areas of the skin.

> I may remark that some of the lowest organisms, in which nerves cannot be detected, are capable of perceiving light, it does not seem impossible that certain sensitive elements in their sarcode [protoplasm] should become aggregated and developed into nerves, endowed with this special sensitivity.

He quotes an M. Jourdain as finding

> …aggregates of pigment cells, apparently serving as organs of vision, without nerve cells and resting merely on protoplasm that serve only to distinguish light from dark. In certain star-fishes *[sic]*, small depressions in the layer of pigment which surrounds the nerve are filled with transparent gelatinous matter, projecting with a convex surface, like the cornea of higher animals…this serves not to form an image, but only to concentrate the luminous rays and render their perception more easy *[sic]*.

Darwin described numerous other intermediate forms of light and image perceiving organs. For example, bacteria are able to swim toward the light using

nothing more than a nerveless, lensless patch of pigment containing light sensitive material. In essence he pointed out that the eye is not irreducibly complex because some organisms had primitive but functioning parts of the whole.

A Computer Model of the Evolution of Refractory Index

The eye is a unique organ for a computer-based analysis of evolution because specific numbers can easily represent the structures necessary for image formation. In this case the quantified variable is visual acuity or spatial resolution. It is the sole reason for the eye's optical design and is measured in terms of the ability for each photoreceptor to have a different field of view.[2] Nilsson and Pelzer[3] felt that the evolution of visual acuity of the vertebrate, pinhole-type of eye was especially amenable to examination by a computer simulation program.

They started with a simple patch of light-sensitive cells that was backed and surrounded by dark pigment.

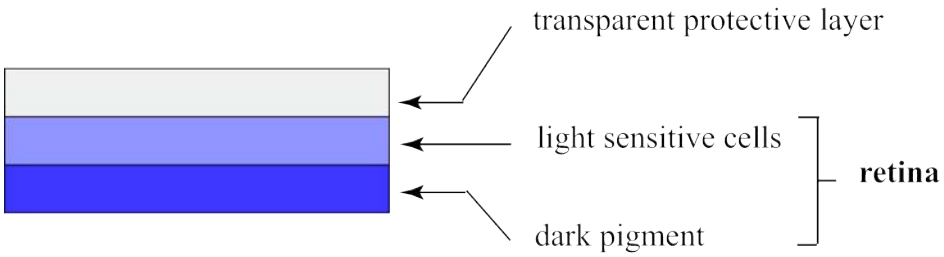

Figure 1. Initial stage of the Nilsson and Pelzer[3] simulation of the evolution of morphological aspects of the eye.

They then exposed this to selection for better and better visual acuity. There were two possible ways for this to occur: A) by forming a central depression in the light sensitive patch or B) by developing the pinhole. Both would reduce the angle through which the individual light-sensitive cells receive light. They found that initially deepening the pit was by far the most efficient. However, at a certain point, decreasing the aperture by forming the pinhole was more efficient. As the aperture decreased, the amount of light entering the eye also decreased. At a certain other point a further increase in visual acuity was only possible with the addition of a lens. Unlike man-made lenses, biological lenses do not have the same refractive index throughout. A smooth gradient of refractive index offers a superior design.

Nilsson and Pelzer made a conservative estimate that each evolutionary step based on genetic variation would make a one percent change in any quantitative character. The calculated number of one percent changes required between each stage was plotted against the number of resolvable image points within the eye's visual field. This showed that the spatial resolution improved almost linearly with morphological changes *indicating there were no particularly difficult steps in the process.* Figure 2 summarizes the different changes in the structure of the eye over time and the number of steps between each stage. The relative change in receptor diameter required to keep the light sensitivity constant throughout the sequence is represented by the letter *d*.

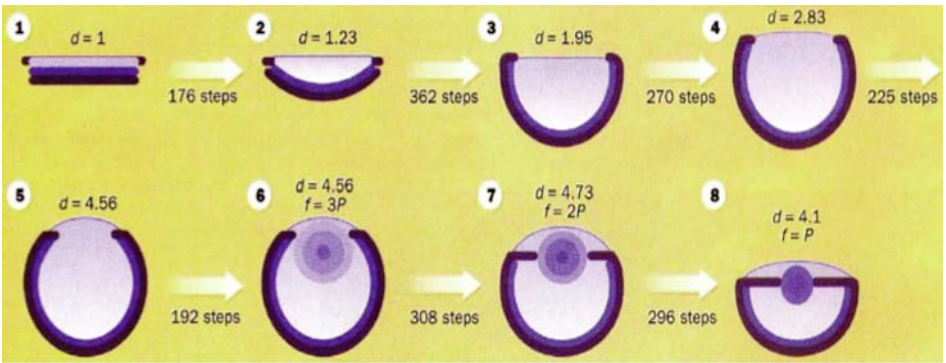

Figure 2. Stage 1 is as shown in shown in Figure 1. In successive stages the top protective layer deepens to form the vitreous body of the eye. The refractive index of the vitreous body is assumed to be 1.35, which is only slightly higher than water. In stages 4 and 5 the retina continues to grow (increasing d*) but without changing the radius of the curvature. This causes a gradual shift from deepening the retinal pit to construction of the pinhole. In stages 6 to 8 a graded refractory index lens appears with a local increase in refractive index. The central refractive index increases from an initial 1.35 to 1.52. Simultaneously the lens changes shape from ellipsoid to spherical and moves to the center of the curvature of the retina. As the lens shrinks, a flat iris gradually forms by stretching of the original aperture. The focal length (f) of the lens gradually shortens, and in stage 8 it equals the distance to the retina (P), producing a sharply focused system. Figure from Nilsson and Pelzer.* [3] *By permission from* Proc Biol Sci. *256: 53-58, 1994 as modified by Dawkins.* [1]

Nilsson and Pelzer made a great effort to keep the model conservative. Thus, they allowed only a one percent change at each step and excluded parallel steps. Each step had to occur in series, a caveat that eliminated Behe's concerns that multiple simultaneous steps would be unlikely. Using additional conservative values for the selective advantages of each step, they estimated the entire process could be completed in fewer than 400,000 steps. In an article entitled "The eye in a twinkling," Dawkins [1] stated,

> …the time needed for the evolution of the eye, far from stretching credulity with its vastness, turns out to be too short for geologists to measure. It is a geological blink.

Figure 3 shows a collection of different eyes from a simple eyespot to the complex eye, which has occurred independently at least a dozen times in natural history. This shows that the stages shown in Figure 2 are not purely theoretical but have some basis in real evolution.

The many different functioning eyes, from simple to complex, again illustrate that the eye is not irreducible. The fact that evolution produced so many different solutions to the need to see, and produced them many different times, indicates that eyes are not an impossibly complex problem for evolution.

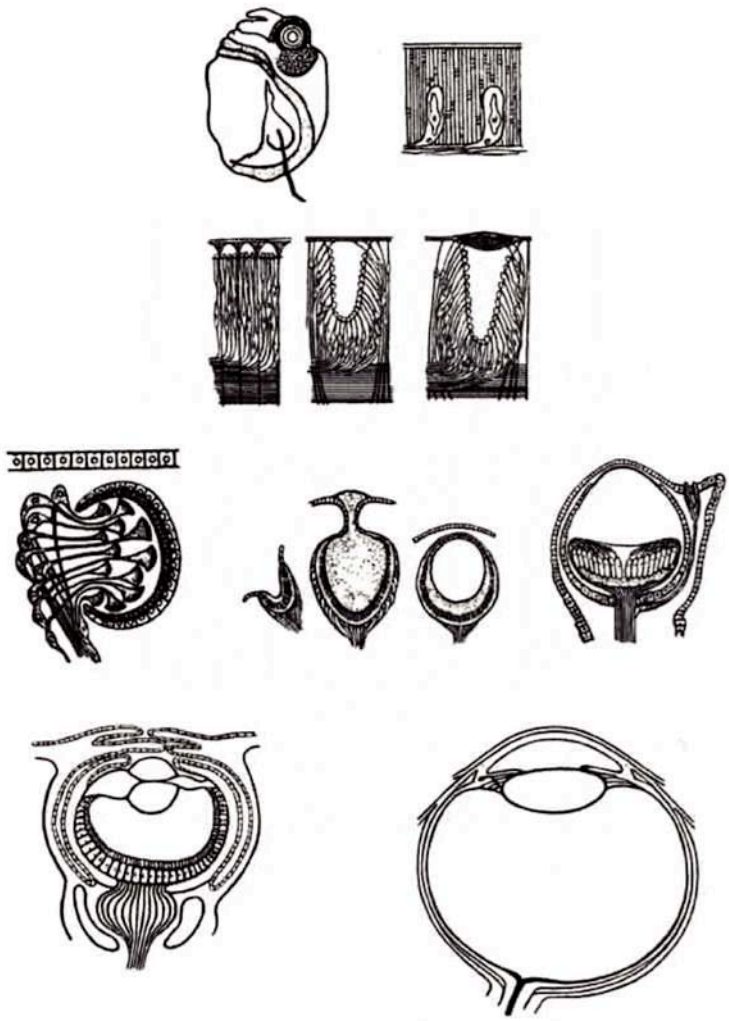

Figure 3. Eyes ranging from a single eyespot to a complex eye. From Michael Shermer, How We Believe. *2000.*[4] *By permission.*

In his section on "Organs of Extreme Perfection and Complication," Darwin himself recognized that while the eye was a challenge for his theory, there was plenty of evidence to suggest it evolved by many small steps, starting with a simple light-sensitive patch. Evolution has produced many different types of eyes, from simple to complex, many different times, indicating eyes are not irreducible and not an impossibly complex problem. Since many aspects of the eye can be easily reduced to numbers, Nilsson and Pelzer were able to perform a computer simulation of the evolution of

the eye using tiny, non-overlapping steps. Despite using very conservative parameters, they found the modern eye could evolve in less than 400,000 generations—a blink of the eye in geological time.

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With maleus
Aforethought
Mammals
Got an earful of their ancestors
Jaw

John Burns
Biograffiti, 1975 [1]

Chapter 9

Complexity—Ears

Fish hear by sensing the vibrations in the water. These vibrations pass through sensory organs called lateral lines that run along the side of the body. Small neuromast structures sense this vibration and activate sensory nerves that pass these sensations to the inner ear located near the head. This system is very efficient because water is dense and the energy conveyed by vibrations is quite sufficient to activate the sensory nerves of the lateral lines and then the hearing apparatus of the inner ear.

Evolution then took a giant step and some animals evolved from fish to land based tetrapods. The inner ear, with its sensory hairs embedded in a liquid medium, remained fundamentally the same as for fish. But there was a problem. Air is much less dense, than water and it was now necessary to develop a method of amplifying the weak vibrations in air into vibrations that were strong enough to move the liquid in the inner ear.

Evolution of the Mammalian Jaw

The mechanism by which this took place is intimately wrapped up with the complaint by creationists that evolution from the jaw of the reptiles to the jaw of mammals was impossible since no intermediates had been found. The committed young earth creationist Duane Gish especially advanced this position in his 1978 book, *Evolution? The Fossils Say No:* [2p80]

> All mammals, living or fossil, have a single bone, the dentary, on each side of the lower jaw, and all mammals, living or fossil, have three auditory ossicles or ear bones, the malleus, incus and stapes…Every reptile, living or fossil, however, has at least four bones in the lower jaw and only one auditory ossicle, the stapes…There are no transitional fossil forms

showing, for instance, three or two jawbones, or two ear bones. No one has explained yet, for that matter, how the transitional form would have managed to chew while his jaw was being unhinged and rearticulated, or how he could hear while dragging two of his jaw bones into his ear.

With some modifications the same charges were repeated in his 1995 book *Evolution: The Fossils Still Say No.*[3] The following diagrams illustrate the issues. In the reptile *Pelycosaur*, the squamosal bone is just above and makes contact with the quadrate (Figure 1, in light blue).

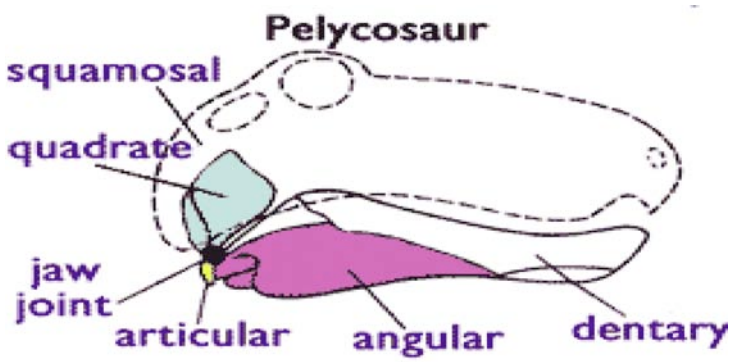

Figure 1. Reptile (Pelycosaur) jaw. From Kardong, Vertebrates. Comparative Anatomy, Function, Evolution. *McGraw Hill, 2002.*[4p275] *By permission.*

The jaw joint (black) consists of an articulation between four bones: the quadrate, articular, angular and dentary bones. By contrast the early mammalian jaw is shown in Figure 2.

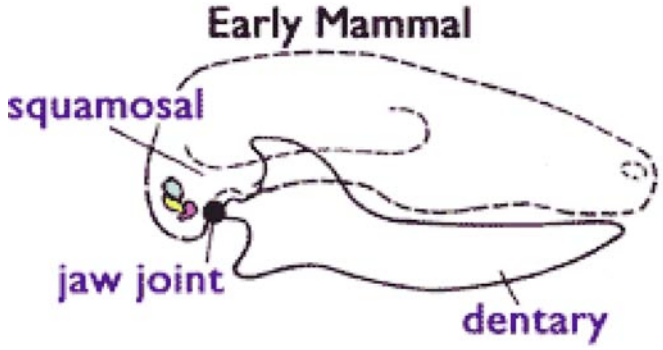

Figure 2. Early mammalian jaw. From Kardong, 2002.[4p275] *By permission.*

Here the jaw joint (black) consists of an articulation between two bones, the dentary and the squamosal. The quadrate has become the incus (blue), the articular

has become the malleus (yellow), and the angular has become the stapes (pink). Thus, the issue raised by creationists was "how the transitional form would have managed to chew while his jaw was being unhinged and rearticulated, or how he could hear while dragging two of his jaw bones into his ear." Figure 3 shows the *Therapsid* transitional intermediate and provides the answer.

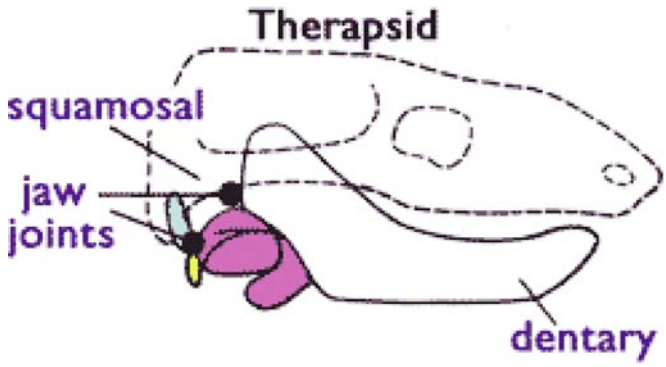

Figure 3. Therapsid jaw. From Kardong, 2002. [4p275] *By permission.*

This intermediate form has two jaw joints, retaining the reptile joint consisting of the articulation of only three bones, the quadrate (blue), the angular (pink) and now the articular (yellow). This freed up the dentary to form a second mammalian-like jaw joint with the squamosal bone. This, in turn, freed the quadrate to become the incus, the angular to become the stapes (pink) and the articular to become the malleus (yellow).

The positioning of these three early bones in the human ear is shown in Figure 4.

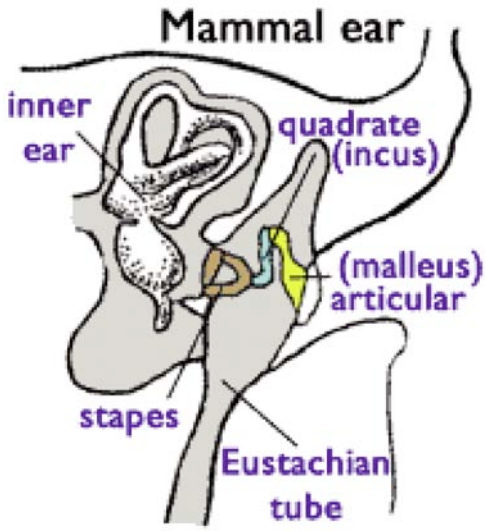

Figure 4. Human ear. Quadrate—incus (yellow), articular—malleus (yellow), and stapes (pink). From Theobald. [5] *By permission.*

Three little bones in the middle ear of mammals serve to amplify the weak vibrations in air so they can move the fluid in the inner ear and translate sound into nerve transmissions.

I have presented the evolution of the mammalian ear because it illustrates so well the dictum enunciated by Gould [6p101] that "Complex creatures exist by virtue of slop, multiple use, and redundancy." For example, the major purpose of the early stapes was as a structural support of the jaw.[7] It had a minor role in respiration and in hearing. When the jaw articulation was shifted to the squamosal-dentate of the mammalian version, the stapes was now redundant slop and free to shift to hearing as its major function. After the articulation of the squamosal and the dentary bones, a similar redundancy allowed the quadrate and the articular bones to shift from a primary function of support to a primary function of hearing. This point about multiple use and redundancy in evolution will be repeated in subsequent chapters.

The evolution of the ear well illustrates the dictum, "Complex structures exist by virtue of slop, multiple use, and redundancy." All three bones of the mammalian ear became slop and redundant when their prior function as part of the reptilian jaw was replaced by other bones. They could then be used for the critically important task of hearing.

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Chapter 10

Complexity—The Citric Acid Cycle

One of the most important things that a living cell needs is energy. In all forms of life this energy is supplied by a high-energy phosphate-phosphate chemical bond provided by a compound called ATP or adenosine tri-phosphate. This structure is shown in Figure 1.

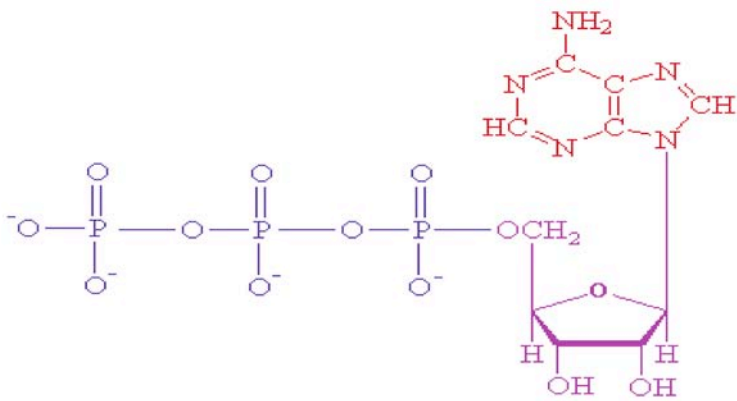

Figure 1. ATP. Adenine is in red, ribose in magenta, and the chain of three phosphate groups is shown in blue. [1]

The third phosphate group is the one that carries the high-energy bond and serves as the energy source of the cell. This chemical form of energy currency can be spent in many different chemical reactions in the organisms that need energy to work. The primary source of the energy is glucose (sugar). One sugar molecule is converted into as many as 38 ATP molecules. The first stage of this process is called glycolosis. This converts glucose into two pyruvate molecules and in the process produces 6 ATPs. An enzyme called pyruvate dehydrogenase converts pyruvate + coenzyme A (coA) to acetyl-coA, which is then converted by another enzyme into oxaloacetate. This is then passed through a series of eight chemical reactions using eight different enzymes, ending up again with oxaloacetate. The whole cycle is called the *citric acid cycle.* It is also called the *Krebs cycle,* after the biochemist Hans Krebs who first worked it out. It is shown in Figure 2.

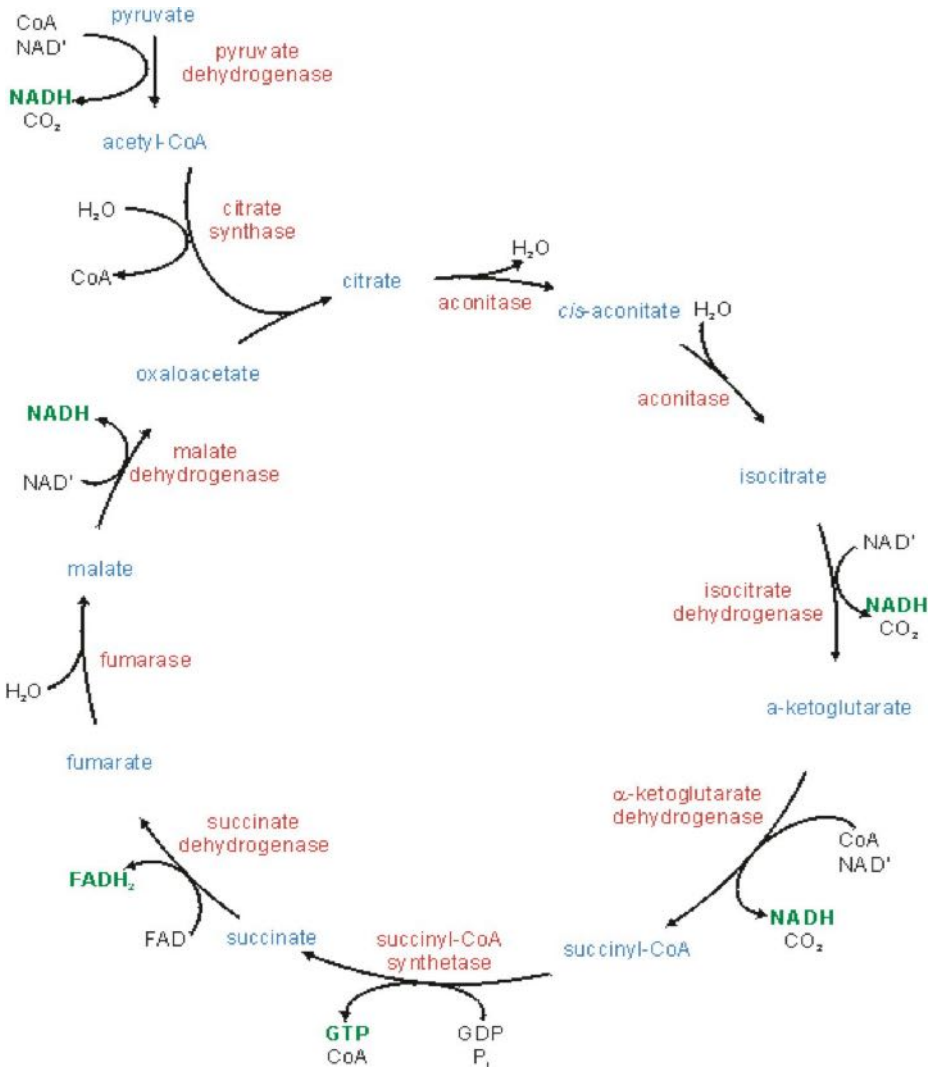

Figure 2. The citric acid cycle. The cycle starts with oxaloacetate and progresses through eight other chemical structures (blue) before ending up again with oxal-acetate. Names of the enzymes involved are in red. The various cofactors are in green. From www.pnf.org.

Talk about complex! The citric acid cycle is both one of the most important and most complex of the metabolic pathways. Surely if there was ever something with "irreducible complexity," this should be it. If this can be the product of Darwinian evolution, anything can. But how? Two research groups, Melendez-Hevia and colleagues [2] and Huynen and colleagues [3] have examined the evolution of the citric acid cycle. Melendez-Hevia and colleagues [2] pointed out that the citric acid cycle was the result of opportunism in molecular evolution.

Their introductory remarks are highly relevant to the issues raised by Intelligent Design and creationism.

> During the origin and evolution of metabolism, in the first cells, when a need arises for a new pathway, there are two different possible strategies available to achieve this purpose: (1) create new pathways utilizing new compounds not previously available or (2) adapt and make good use of the enzymes catalyzing reactions already existing in the cell. Clearly, the opportunism of the second strategy, when it is possible, has a number of selective advantages, because it allows a quick and economic solution of new problems. Thus, in the evolution of a new metabolic pathway, new mechanisms must be created only if "pieces" to the complete puzzle are missing. Creation of the full pathway by a *de novo* method is expensive in material, time-consuming, and cannot compete with the opportunistic strategy. [1]

It was found that only one "new" enzyme was needed to complete the citric acid cycle—succinyl-CoA synthase (see Figure 2). *All the other steps previously existed for a different purpose*.

In their study of the evolution of the citric acid cycle, Huynen and colleagues examined 19 different genomes that had been completely sequenced by 1999. These included four Archea, 14 Bacteria, and one Eukaryote. Many of these organisms still generated ATP despite missing one or more of the involved enzymes. In addition, for many of the organisms some reactions were catalyzed by more than one enzyme, a situation they called non-homologous gene replacement. This is equivalent to the evolutionary opportunism of Melendez-Hevia. Many of the enzymes involved had more than one function. Thus, the citric acid cycle was both reducible and modular.

Many of the mechanisms described in this chapter and Chapter 6, including horizontal gene transfer, gene duplication, domain, exon and sub-exon exchange, gene displacement, and evolutionary opportunism, were utilized in the evolution of the citric acid cycle. In summary, Melendez-Hevia and colleagues stated:

> The Krebs cycle was built through a process that Jacob [4] called "evolution by tinkering," stating that evolution does not produce novelties from scratch. It works on what already exists. The most novel result of our analysis is seeing how, with minimal raw material, evolution created the most important pathway of metabolism, achieving the best chemically possible design. In this case, a chemical engineer who was looking for the best design of the process could not have found a better design than the cycle which works in living cells. [2]

The citric acid cycle is an extremely complex metabolic pathway that is critical for energy production by living cells. Despite being complex it is highly reducible. Multiple different evolutionary mechanisms were involved in its evolution, including horizontal gene transfer, gene duplication, domain, exon and sub-exon exchange, gene displacement, and evolutionary opportunism. The citric acid cycle is an outstanding example of how complex pathways can be the product of a rich range of evolutionary tools.

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Chapter 11

Complexity—Blood Clotting

Like each of the systems discussed in previous chapters—vision, hearing, and energy production—the ability to keep from bleeding to death after an injury is also critical to survival. In vertebrates this has evolved into a complex, multi-step cascade that progressively and quickly amplifies the signal as the cascade progresses, finally providing for the development of a large fibrin blood clot to stem the potentially lethal flow of blood from a wound. This cascade can be set off by an extrinsic system responding to tissue damage, or an intrinsic system responding to vascular insults. The relationship of these two systems is shown in Figure 1 (next page).

The initial resting or inactive proteins are in red. These proteins are cut by an enzymatic reaction called *proteolysis.* The resultant products are in green or yellow. The enzymes doing the cutting are called *proteases.* Because they act at sites where the amino acid *serine* is present, they are called *serine proteases.*

If any one of the steps are left out, clotting does not occur or occurs too easily. Because of this, Behe [2] termed this a system of irreducible complexity and thus an example of Intelligent Design. As is true of most complex systems, he was not the first to wonder how they could have evolved. Russel Doolittle spent a lifetime researching the evolution of blood clotting. When he was a graduate student in the 1960s he asked himself, "How in the world did this complex and delicately balanced process ever evolve?" [3] In contrast to Behe, who simply threw up his hands and only heard the piercing cry of "design!", Doolittle set about attempting to answer the question in a more scientific manner.

Evidence that the cascade did not evolve all at once came from a careful examination of the molecular evolution of the clotting proteins see Table 1 (end of chapter) illustrates the fact that the first set of coagulation factors made their appearance 900 million years ago, while the last addition was only 200 million years ago.

The evolution of the clotting factors is a classic tale of gene duplication and exon and domain shuffling (Figure 2). As discussed previously, domains are segments of genes that have a proven function and can be exchanged between genes and used to facilitate the rapid evolution of new genes. Some of the domains involved in the clotting proteins are the GLA (**G**) domains that contain multiple γ-carboxy-glutamic acid residues whose synthesis depends upon vitamin K; EGF or epidermal growth

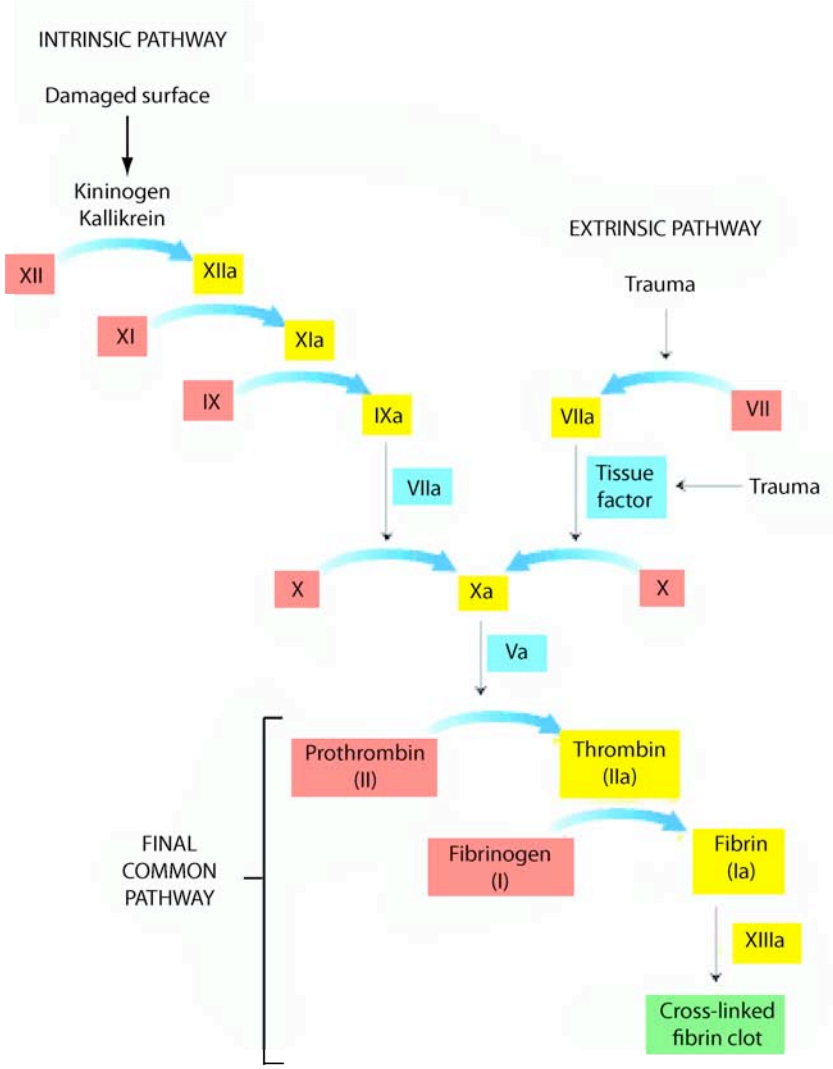

Figure 1. The blood clotting cascade.[4a] *See text.*

factor domains (E); kringles (K) which are modules involved in protein-protein binding[4]; PAN or proteasone-activating-nucleotidase domains involved in protein folding (P); fibronectin 1 (F1) and fibronectin 2 (F2) domains involved in cell adhesion; and serine protease (SP) domains. The details of what all these domains do are not as important as the concept that most of the coagulation proteins share many functions in common because they share many domains in common.

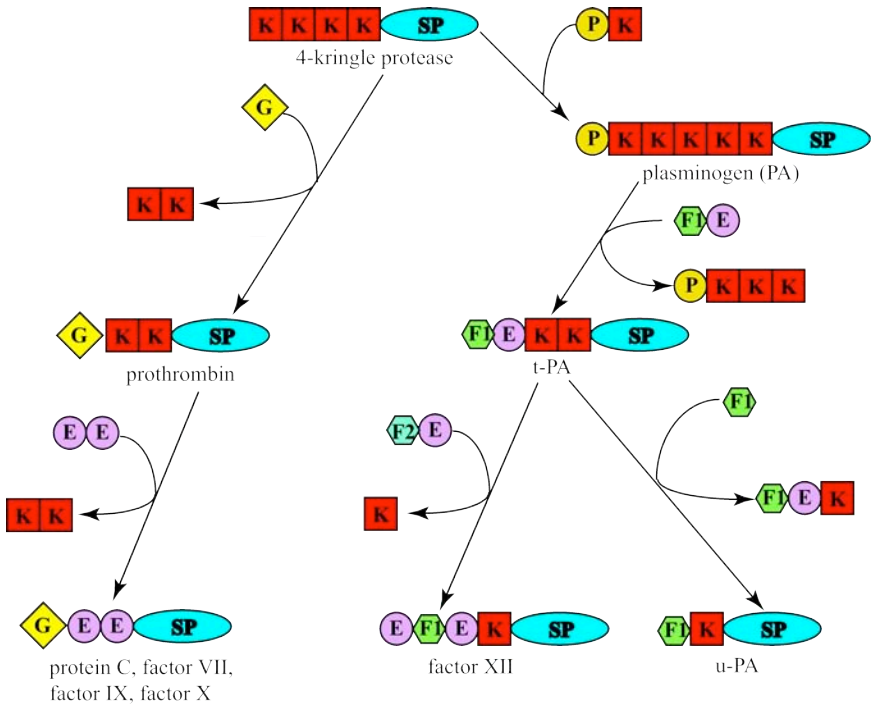

Figure 2. Evolution of coagulation factors. From Jiang and Doolittle, The evolution of vertebrate blood coagulation as viewed from a comparison of puffer fish and sea squirt genomes. PNAS. *100:7527-7532.*[6] *By permission of the National Academy of Sciences, USA. Copyright 2003.*

Figure 2 shows how the different coagulation proteins can evolve from a common 4-kringle-serine protease precursor similar to that found in the sea squirt. As stated by Doolittle,[3] "This bespeaks of a wild frenzy of gene duplication and exon shuffling during a relatively brief episode just before the appearance of true vertebrates."

The mechanism of the evolution of the complex blood clotting cascade is understandable when it is observed that different components did not appear all at once but developed over a period of 400 million years and that most of the proteins involved are closely related serine proteases whose similarities are accounted for by gene duplication and whose differences are accounted for by the shuffling around of a small number of different functional domains.

How did the cascades evolve? In attempting to defend himself against the criticisms of his use of the blood clotting system as an example of irreducible complexity, Behe[2] criticized the invoking of gene duplication and exon shuffling as "so much hand waving." He claimed that gene duplication was irrelevant since it was not evidence *per se* for natural selection. This claim ignores the fact that gene

duplication and natural selection are extremely interwoven concepts. As described previously, due to the power of gene duplication there are now two copies of a gene, one copy can continue to carry out its original function. Natural selection ensures that any mutations of the original gene would not be tolerated since they would likely reduce the fitness of the organism. At the same time, freedom from elimination by natural selection allows the duplicated gene to experiment with a number of random mutations. If, by chance, those changes provide a new function that is advantageous to the organism, natural selection now increases the fitness of the organism. Thus, *gene duplication has natural selection written all over it.*

Often when the environment changes there is a selective advantage to developing a new function. An Intelligent Design or supernatural solution would simply be a wave of God's hand and voilá—there would be a new gene. Since there are thousands of permutations of different amino acid sequences that could accomplish this task, the chance that the sequence of the new gene would resemble the sequence of any old gene would be remote. In fact, because of gene duplication, there is extensive similarity between the sequence or the old gene and the new gene. This alone falsifies the ID hypothesis and validates the process of evolution.

Behe's related complaint is that gene duplication and exon shuffling does not explain why nature found it necessary to build complicated multiple layers of actions into the blood clotting system and how it was done. Table 1 provides some clues and helps to answer Behe's complaint. The clotting system of 900 million years ago included only fibrinogen, prothrombin, tissue factor, and plasminogen. Figure 3 shows what such a system would look like back in the Precambrian or Proterzoic eon, when only the extrinsic pathway was in place. Clotting was adequate for the primitive, low-blood pressure organisms of that time. This illustrates what I mean by *pseudo-irreducible*.

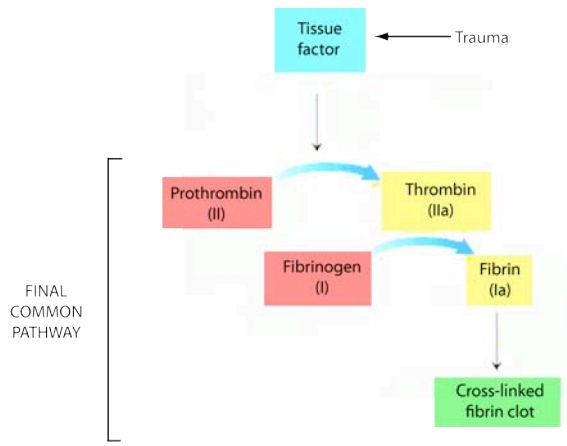

Figure 3. Figure 1, but with only the clotting proteins that existed in the Precambrian time.

If all the parts missing in Figure 3 were removed from a modern vertebrate, they would quickly bleed to death following injury. But the low "blood pressure"

Precambrian organisms obviously fared well—thus the term *pseudo-irreducible*. With this clotting system, trauma elicits the release of tissue factors. Factor X and Factor V are not yet present. These primitive organisms do not have an intrinsic clotting system because an elaborate vascular system did not exist. Clotting was a very simple system consisting of the conversion of fibrinogen to fibrin by the action of thrombin presumably produced by the direct action of tissue factor on prothrombin.

The modern clotting system is almost unique in requiring a finely tuned system of checks and balances. Too little clot and the organism bleeds to death. Too much clot and the organism dies of excessive thrombosis. Thus, as animal life evolved into more complex organisms with a better vascular system, there was also a need for an intrinsic activating system.

Five hundred million years ago Factors V, VII, X and XII were also present. Figure 4 (next page) summarizes this clotting pathway. The whole progress is now largely restricted to fine-tuning the extrinsic pathway. This makes sense because the Cambrian organisms still had a low-pressure primitive vascular system. The major dangers are still from external injury. Now, instead of acting directly on prothrombin, tissue factor acts by interacting with a series of serine protease factors VII, V, and X, all of which are easily produced by gene duplication.[3] Factor XII has come into existence as a primitive start of the intrinsic activating system. As a serine protease it can easily serve the function of Factor IX of later systems, also a serine protease.

Subsequent steps in evolution act to fine-tune this system. Thus, contrary to Behe's complaints, the slow addition of layers of the coagulation system over time—first to fine-tune the extrinsic system, then to initiate the intrinsic system, and finally to enhance sensitivity and provide for a more rapid response system when the increase in blood pressure makes a rapid response critical to survival—is both reducible and easy to understand.

The clotting system is not irreducible. In primitive Precambrian organisms, the presence of only fibrinogen, prothrombin, tissue factor, and plasminogen worked well for an extrinsic activation-only system in organisms with a primitive vascular system and low "blood pressure." Over the next 400 million years the major advance was to fine-tune the extrinsic activation system using two related serine proteases. Since that time, as the vascular system improved and blood pressure increased, there was a fine-tuning of the intrinsic activating system. These steps make the progressive addition by natural selection of multiple steps in the cascade easy to understand. This is hardly the picture of an irreducibly complex system that requires a divine creator to bring into existence all at once.

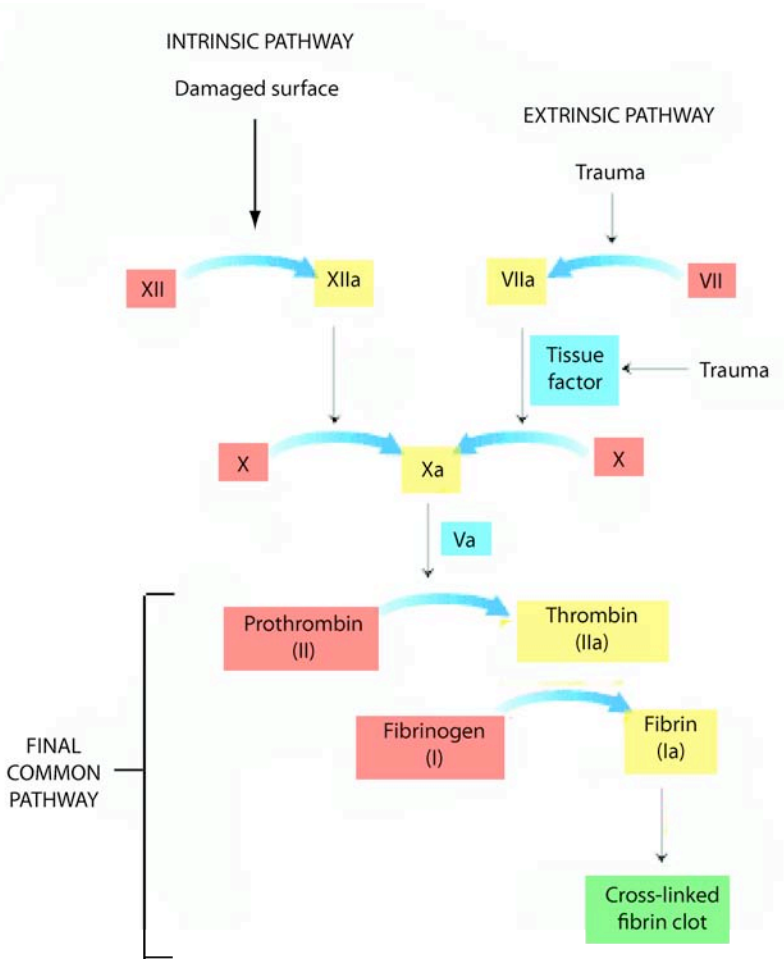

Figure 4. Clotting proteins as of 500 million years ago.

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1. Figure from from wiki.cotch.net/index.php/Blood_clotting. By permission.
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4a. From wiki.cotch.net/index.php/Blood_clotting. By permission.

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Table 1. An Inferred Order of Appearance of Some Blood-Clotting and Fibrinolytic Proteins. *From Doolittle and Feng.* [4]

Factor	**Million Years Ago**
Fibrinogen	900
Prothrombin	
Tissue factor	
Plasminogen	
Factor V	500
Factor VII	
Factor X	
Factor XII	
Factor VII	450
Factor IX	
Factor XI	
Prokalikrein	200

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Chapter 12

Complexity—Cilia

Cilia and flagella are high on the list of examples proposed by Intelligent Designers as showing irreducible complexity. Since cilia are a subpart of flagella, I will examine them first. Cilia are fine, hair-like structures that beat like a whip and are used to either aid in the locomotion of a cell like a sperm or to move objects around the outside of a cell. In the respiratory tract, cilia serve to move dust and other particles out of the lungs. A cross section of a typical cilium is shown in Figure 1.

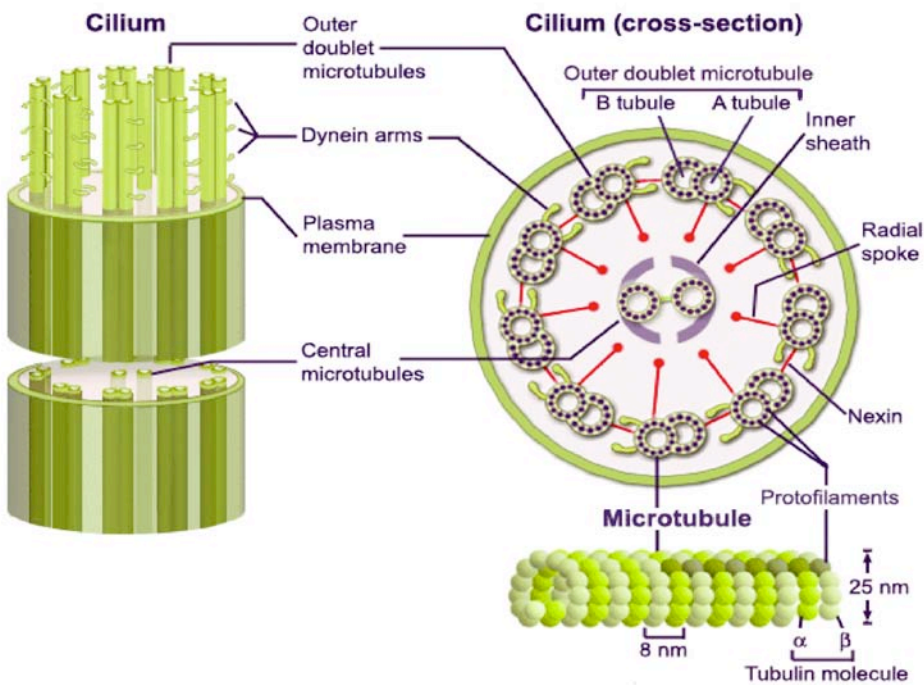

Figure 1. Structure of a lengthwise (left) and cross-section (right) of a cilium. [1]

The essence of a cilium is the presence of nine microtubule doublets in an outer circle and two single microtubules in the center. This is referred to as a 9 + 2 pattern. Cyanobacteria possess cilia that are of extremely primitive origin. The motion they provide give them a tremendous competitive advantage [2] by allowing the organism to

pull food toward it and to escape from adversity. The other structures such as dynein and nexin attach to the microtubules and play a role in the mobility of the cilia. The doublets are formed by the fusion of two microtubules. Each microtubule is formed of 13 strands or protofilaments of the protein tubulin. Tubulin comes in two forms, alpha and beta, each with a slightly different amino acid sequence. The slightly different structure allows them to stack on top of each other, like a pile of saucers.

In addition to its role in cilia and flagella, tubulin is a module that also plays a critical role in cell division, where it forms the strands that the chromosomes are attached to during mitosis and plays a role in the transport of compounds inside the cell. Taxol, an important drug in the treatment of breast cancer, works by interfering with the function of tubulin, thus stopping cell division. This observation led to increased interest in the 3-D structure of tubulin. This was worked out by Nogales, Wolf and Downing [3] and is shown in Figure 2.

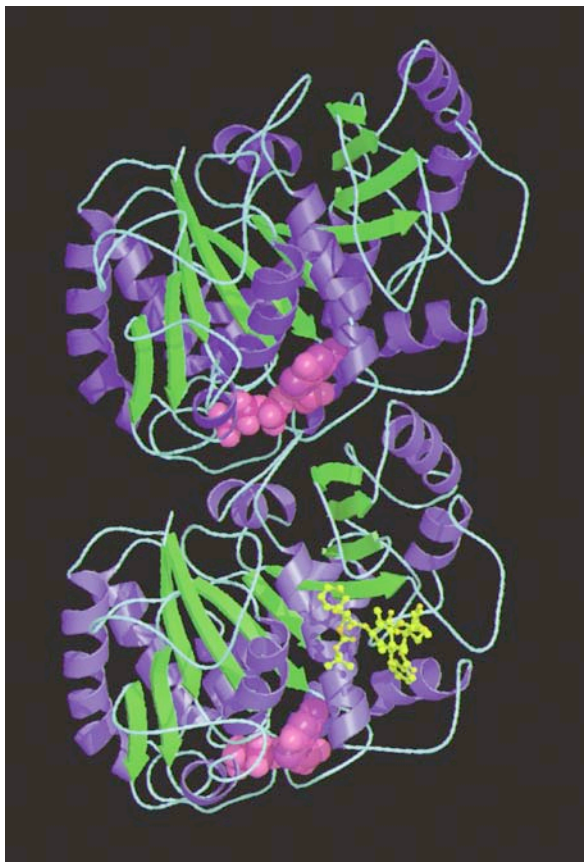

Figure 2. Structure of a tubulin dimer determined by X-ray crystallography at a resolution of 3.7 angstroms. Each monomer is formed by a core of two beta sheets (blue and green) surrounded by helices and each binds to a guanine nucleotide (pink). In addition to a nucleotide binding site, each monomer also has two other binding sites, one for protein and the other for taxol (yellow). From Nogales et al. Cell. *1999.* [3] *By permission.*

Each monomer had three interlinked but different domains, one for binding to nucleotides (guanine in pink), one that binds to drugs like taxol (in yellow), and one that binds to other proteins.

Behe [4] reviewed biochemical studies of the mechanism by which cilia move. The energy for motion is supplied by ATP. When ATP is added to cilia that are stripped of their plasma membrane, they still move normally. However, when stripped of dynein they do not move. Dynein is considered the motor. When stripped of nexin the cilia get longer and longer, indicating the cross-linking by nexin is necessary to prevent this. Behe proposed that since cilia do not move without all three components—the microtubules, the motor and the linker—cilia were irreducibly complex.

Are cilia reducible? There are a number of reports of cilia that are different in structure than the usual form shown in Figure 1. The cilia of insect sperm are a particularly rich source of variation. [6] Many insect cilia show an additional single microtubule next to each doublet and thus have a 9 + 9 + 2 pattern. Some have a 9 + 9 + 1 pattern (Figure 3).

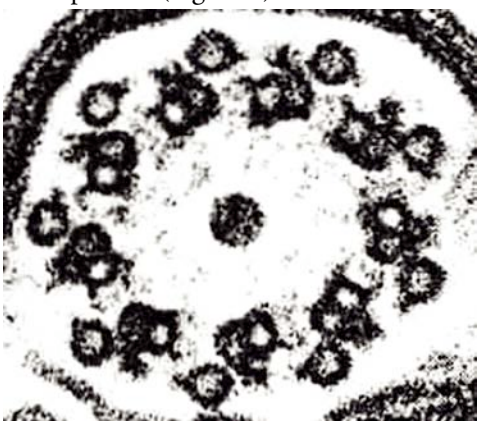

Figure 3. A 9 + 9 + 1 pattern of the sperm flagella of Culex. From Phillips, D. M. Exceptions to the prevailing pattern of tubules (9 + 9 + 2) in the sperm of flagella of certain insect species. The Journal of Cell Biology. *30: 28–43, 1969.* [5] *By permission.*

Some show an absence of the central tubules with a 9 + 9 + 0 pattern (Figure 4).

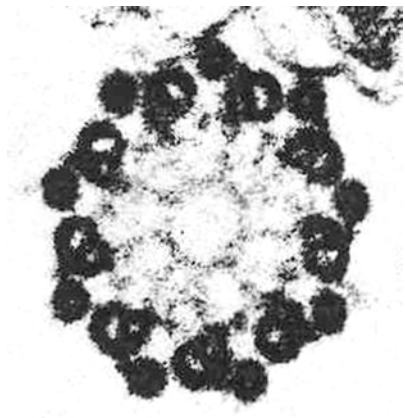

Figure 4. A 9 + 9 + 0 pattern of the sperm flagella of Tricorythodes. *From Phillips, D.M. Exceptions to the prevailing pattern of tubules (9 + 9 + 2) in the sperm of flagella of certain insect species.* The Journal of Cell Biology. *30: 28–43, 1969.* [5] *By permission.*

The absence of the central microtubules is not unique to insect flagella. The eel sperm shows a 9 + 0 pattern (Figure 5).

Figure 5. A 9 + 0 pattern of Anguilla anguilla eel sperm flagella. From Woolley, D. M. Studies on the eel sperm flagellum. J Cell Science. *110: 85-94, 1997.* [6]

In this species, in addition to the missing inner microtubules, the radial spokes and the outer dynein arms were also missing. In addition to a 6 + 0 pattern in Gregarine parasite, [6] a 3 + 0 pattern has been described in another parasite called Diplauxis (Figure 6).

Figure 6. A 3 + 0 pattern in Diplauxis hatti from Prensier et al.: Motile flagellum with a 3 + 0 ultrastructure. Science. *207:1493-1494, 1980.* [7] *By permission.*

The presence of dynein arms could not be excluded. This is the simplest of all cilia yet described. While these simpler forms of cilia are believed to represent loss and modification from an ancestral 9 + 2 pattern, they show that at least as far as the number of microtubules, the radial structures, and the outer dynein arms are concerned, cilia are reducible. Figure 7 shows that cilia are also modular. The dynein was coopted from prexisting brain, muscle and cytoplasmic dynein modules. The microtubule structure was derived from similar structures in mitotic and other cells. The nexin was derived from nestin modules in nerve, muscle and other cells.

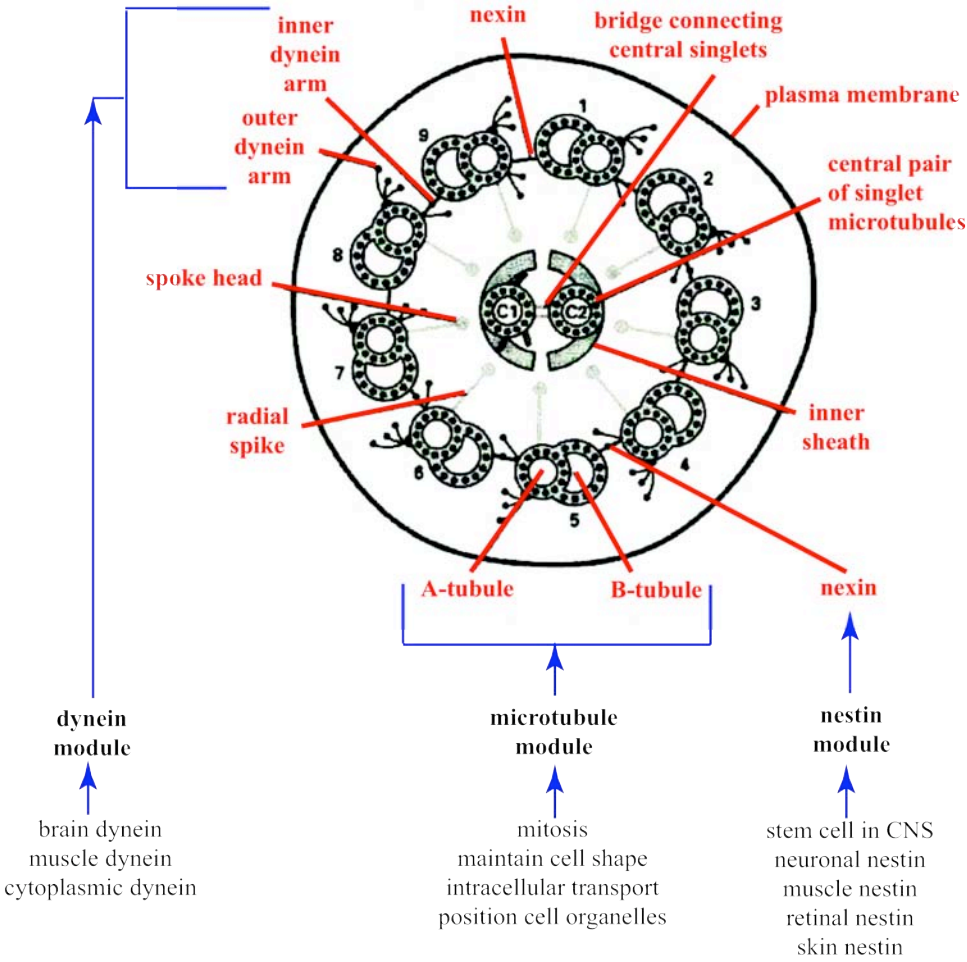

Figure 7. Modular nature of cilia. Each of the major component parts are used in a wide range of other structures and functions. Cilia diagram from Kenneth Miller's Finding Darwin's God. *8*

Thus each of the major component parts of cilia has an independent life elsewhere and thus cilia are highly modular. Even though some of these modules are used in structures that are more complex than bacteria, they illustrate the principle that each of these proteins can have functions that are independent of their function in cilia. Although the examples of simplified cilia such as 9 + 0 without radial arms or outer dynein arms show that the standard cilia are partially reducible, they do not include samples that were totally devoid of dynein and or nexin. Yet the essence of the irreducible complexity argument is that the probability of simultaneously evolving all three structures — microtubules, dynein and nexin — is remote. However, as we have seen in numerous prior examples, such as the citric acid cycle, when the individual components can exist as modules for other functions, cooption

allows them to be assembled into complex structures with a new function. As a task for evolution and natural selection, putting the three cilia modules together would not be difficult.

Cilia are fine hair-like structures that wiggle and beat like a whip. This motion can either move the cell itself or move things outside the cell including food. There are three major component parts of cilia — dynein, nexin and microtubules made of tubulin. The microtubules are usually present as an outer circle of nine doublets and two central singlets. This is called a 9 + 9 + 2 pattern. Dynein and nexin play a critical role in the movement of cilia. Cilia are partially reducible in that they can exist in a much simpler form of 3 + 0, and missing some of the dynein, yet still function well. Cilia are highly modular in that the three major component parts have numerous other uses in other cells. As a task for evolution and natural selection, putting the three cilia modules together would not be difficult.

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Complex creatures exist by virtue of slop, multiple use and redundancy.
Stephen J Gould
Eight Little Piggies [1p101]

Chapter 13

Complexity—Flagella

The bacterial flagellum represents the flagship of the Intelligent Design examples of apparent irreducible complexity [2] and with good reason. They are truly very complex structures. Even published experts in the field have made Behe-like statements. For example, in a 1978 review of bacterial flagella, Macnab [3] stated:

> As a final comment, one can only marvel at the intricacy, in a simple bacterium, of the total motor and sensory system which has been the subject of this review and remark that our concept of evolution by natural selective advantage must surely be an oversimplification. What advantage could derive, for example, from a "preflagellum" (meaning a subset of its components), and yet what is the probability of "simultaneous" development of the organelle at a level where it becomes advantageous?

The key, as usual, is "simultaneous" development. The flagellum of the bacteria *Escherichia coli,* the common bacteria of the human colon, is made up of approximately 20 major proteins and another 20 to 30 proteins that play a role in its construction. [4] Deletion experiments show that with few exceptions, when any of these proteins are removed, the flagellum either fails to function or to be assembled. While this meets the criteria of Behe [2] of being irreducible, it will be seen that this is really pseudo-irreducibility. Although the bacterial flagellum fails to function or assemble when parts are missing, the evolution of the flagellum was highly modular. The presence of many independently functioning modules removes the criteria of the individual parts needing to be "simultaneously" developed. It also eliminates the issue of irreducibility since the modules that were coopted during the process of evolution worked individually, before the other parts were added.

The following discussion relies heavily on the paper by Matzke *Evolution in (Brownian) space: A model for the origin of the bacterial flagellum.* [5] I have presented a fairly detailed description of the evolution of flagella because it plays such a major part in Behe's claims of irreducible complexity. I invite the reader to skip to the **red summary** at the end of the chapter if they are more interested in the conclusion than

the gory details. Figure 1 shows a diagram of the bacterial flagellum with all of its component proteins and genes.

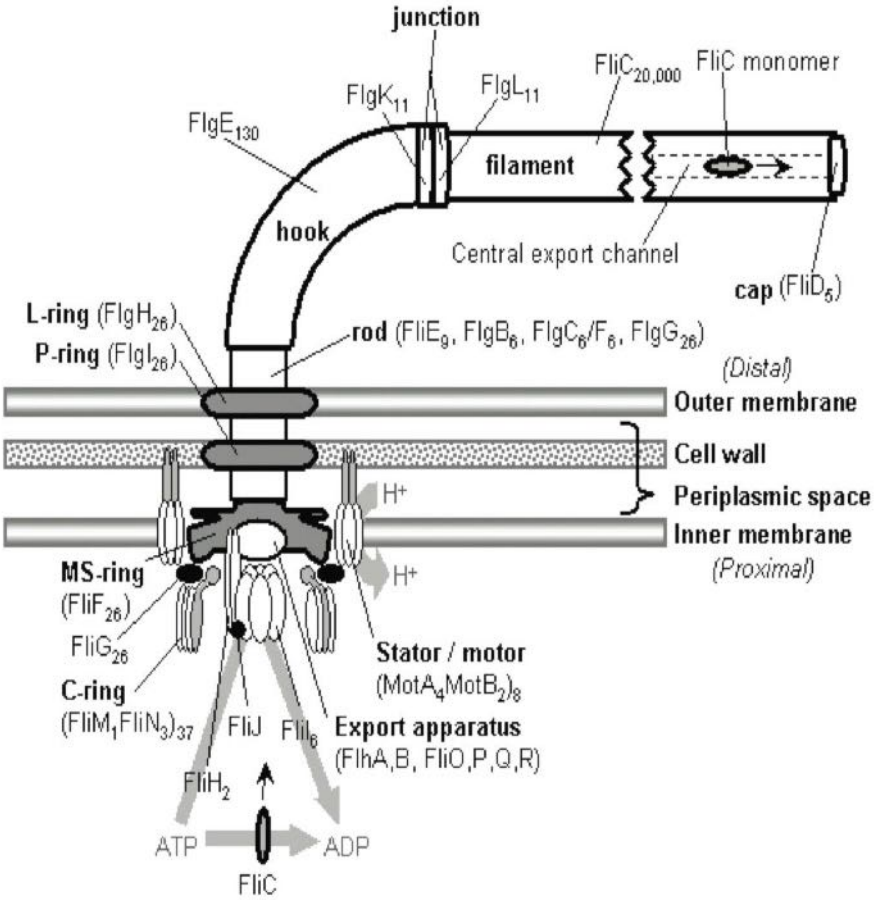


Figure 1. Diagram of a typical bacterial flagellum, shown in cross section. The names of substructures are given in bold, and the names of the constituent proteins are given in regular type. From Matzke.[5] *By permission.*

The cilia described in the previous chapter was a eukaryote flagella composed of tubulin. Bacterial flagella use a different protein called flagellin. The model proposed by Matzke makes extensive use of *cooption* or a shift in function for many of its components. This is a characteristic of a modular system in which a component serves a different prior function and is then coopted for use in the evolution of the flagellum. Figure 2 summarizes the Matzke model.

Stages 1 to 6 are presented in more detail below. Function of the core system refers to the functional state of the flagellum during evolution. Only at the last stage does it have full flagellar function. The analogs refer to the independent functions of the coopted modules before they became part of the flagellum.

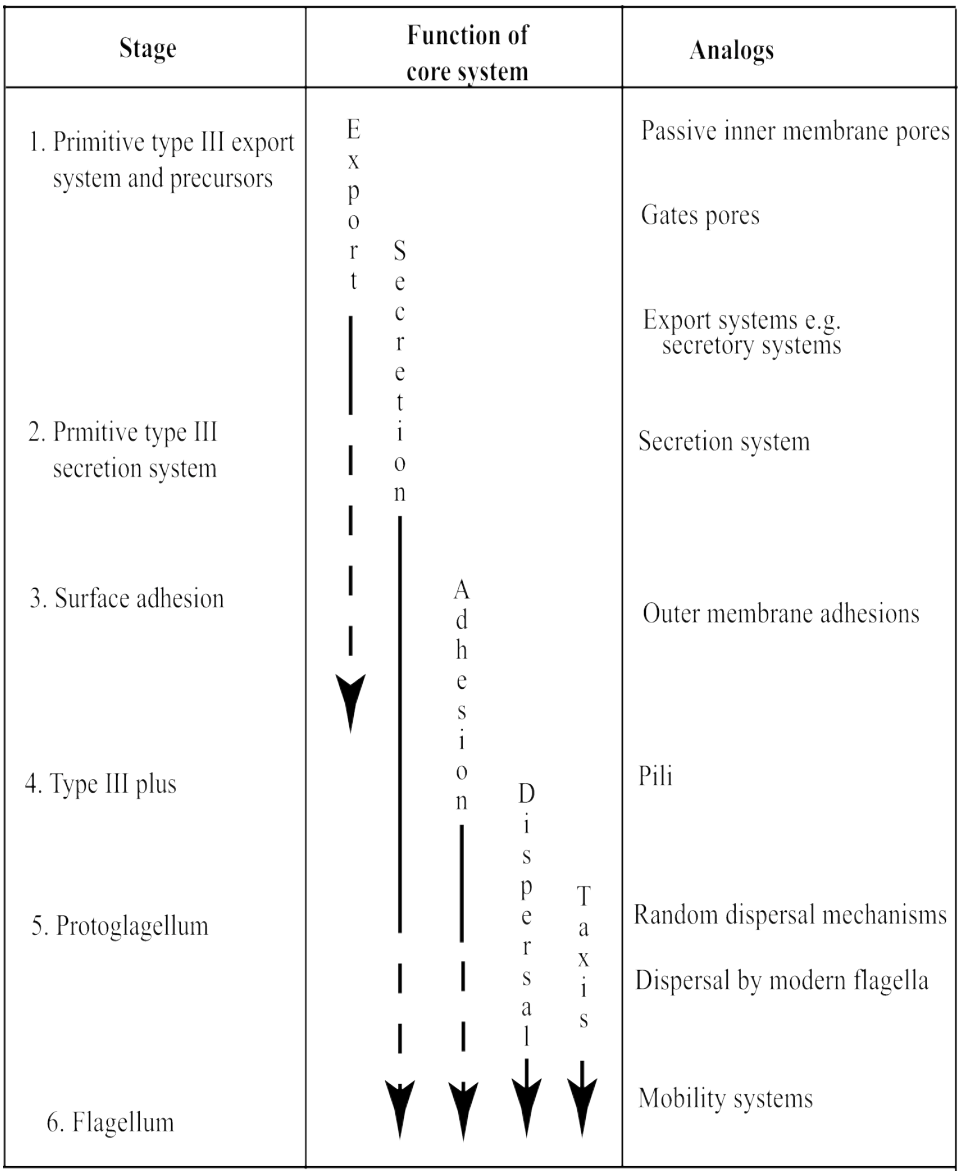
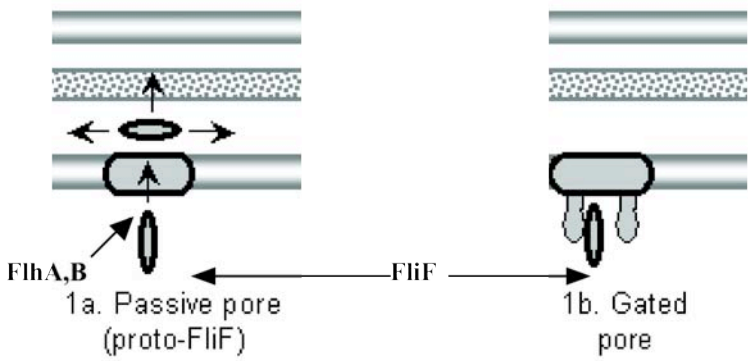


Figure 2. Function and analogs at each stage of the Matzke model.[5] *By permission.*

In the following discussion, the illustrations are all taken from Matzke.[5] Don't be put off by all the strange names. The names are not important; the concept of how this very complex flagellum was able to evolve by extensive use of co- opting other pre-existing modules is important. The structures in white have probable nonflagellar homologs that are coopted to flagellar function. The structures in grey have possible nonflagellar homologs also coopted for flagellar function. Export refers to the transport of proteins from the cytoplasm of the bacteria to the periplasmic space

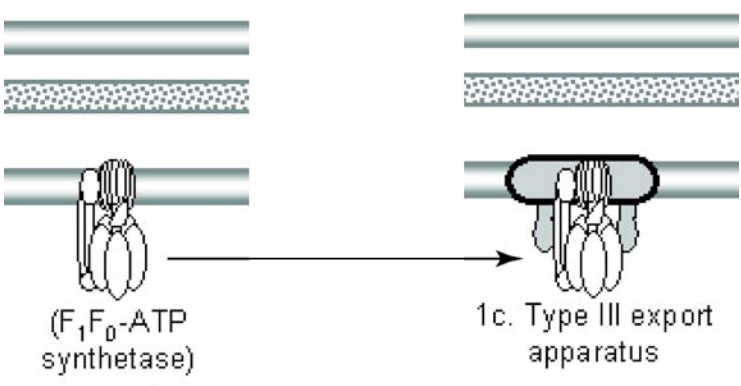
between the inner and outer cell membrane (see Figure 1). When the transport also crosses the outer cell membrane, it is called *secretion*.

The model begins with a primitive-type III export apparatus, with a passive, inner membrane pore (1a) composed of proto-FlhA and FlhB.



The binding of FliF to this pore converts it to a more substrate-specific gated pore (1b) capable of transporting different components of flagellin protein.

As discussed in the section on the citric acid cycle, ATP is the primary currency for energy exchange in living cells. ATP synthase is a critical enzyme for the production of ATP and predated the development of flagella. DNA and protein sequencing studies have shown a 30 percent homology between FliI, a flagellar protein, and the F_1 subunit of F_1F_0-ATP synthase. ATP synthase has a built-in rotor, a perfect object for flagella to coopt for its own rotary purposes.

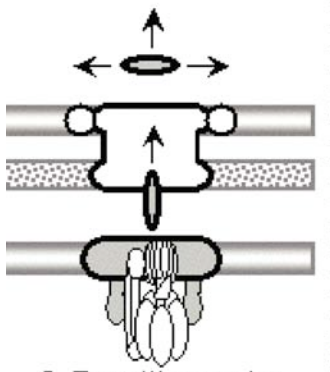


The interaction of an F_1F_0-ATP synthetase with FlhA/B produces an active transporter, a primitive type III export apparatus (1c).

The existence of a non-flagellar type III export apparatus shows that the argument that flagellar components are useless if they are not part of a fully functioning flagellum is not true. It answers McNab's and Behe's question, "What advantage could derive from a preflagellum?" the answer is that it is part of a preexisting module that served as an export system for the bacteria. This is also an

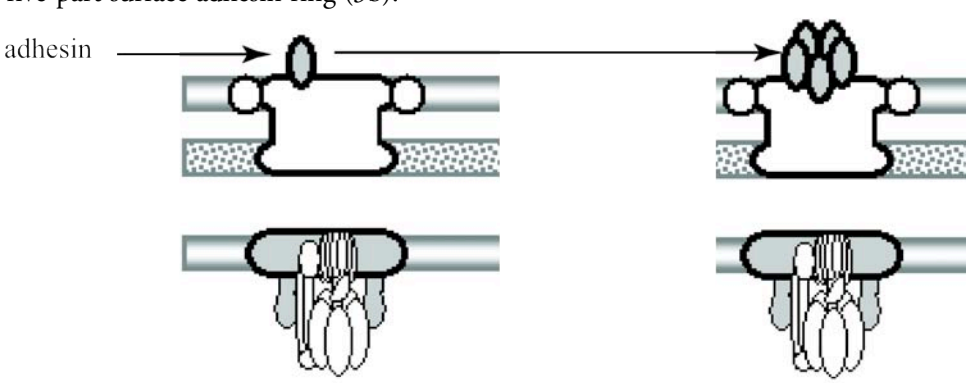
example of what I refer to as a *pseudo-irreducible complex system.* Removing a part may inactivate the modern flagellum but many of its parts were able to function in the past as modules.

Another pre-existing module is the type III outer membrane secretion system. This is the ancient general *secretory (Sec)* pathway for protein secretion by cells.[6] Cooption of a type III secretion system which, with the outer cytoplasmic ring, converts the export apparatus into a secretion system passing through both membranes.



2. Type III secretion system

A bacterium increases its chances of attaching to another structure by secreting adhesion proteins called *adhesins*. These are coopted for use by the flagellum and a mutation lets them bind to the outer side of the secretin (3a) and to then form a five-part surface adhesin ring (3b).

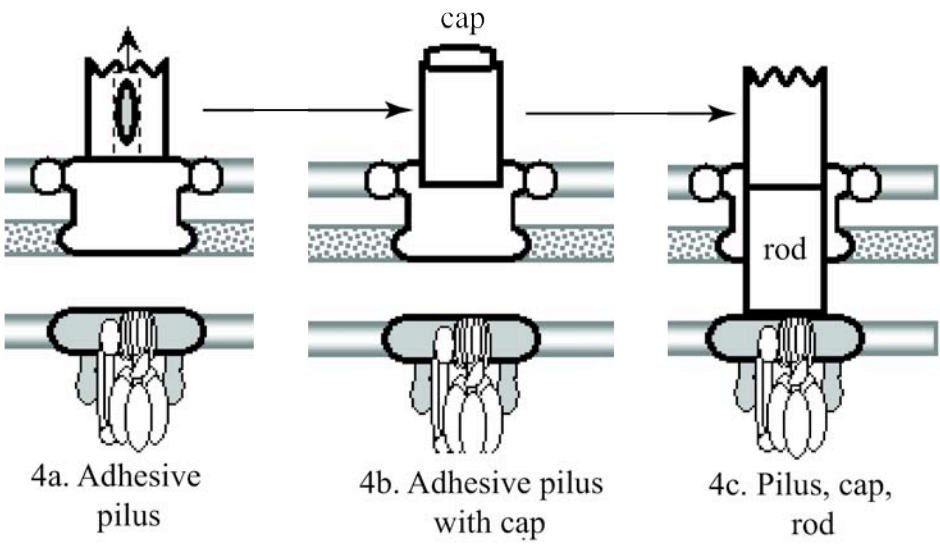


3a. Surface adhesin

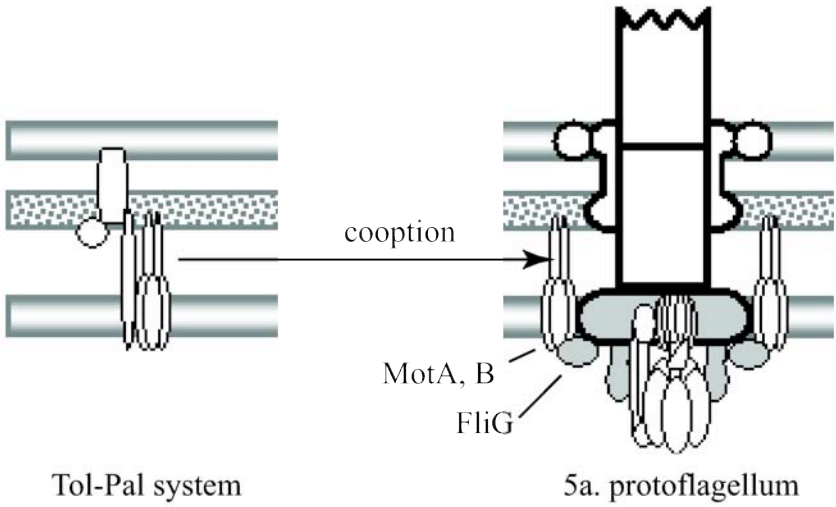
3b Surface with adhesin ring

The polymerization of this ring produces a tube, a primitive type III pilus (4a). All further axial proteins are descended from this common pilin ancestor by gene duplication. The binding together of multiple molecules of a pilin produces the cap that increases the speed and efficiency of assembly (4b). A duplicate pilin that loses

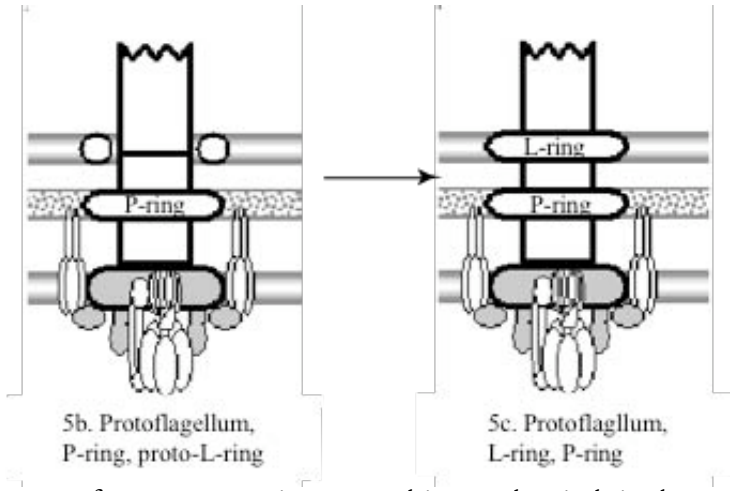
its outer domains becomes the proto-rod protein, extending down through the secretin and strengthening pilus attachment by association with the base (4c).



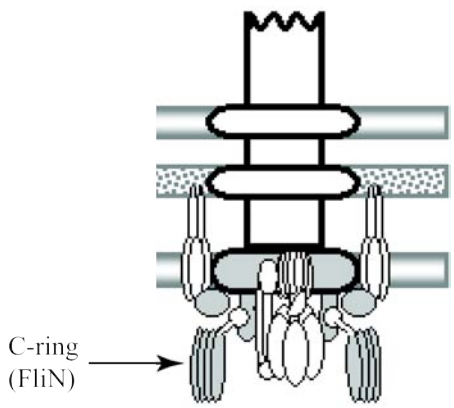
The flagellar motor is made up of two proteins, MotA and MotB. They were derived by cooption of the non-flagellar homologues, the Tol-Pal system,[7] members of the important chemical transport family of proteins that predate flagella. Rotation is aided by the interaction of MotA with FliG attached to the MS ring (FliF). (See Figure 1.)



In order to improve rotation, the secretin loses its binding sites to the axial filament, becoming the proto-P-ring, and the role of the outer membrane pore is taken over by the secretin's lipoprotein chaperone ring, which becomes the proto-L-ring (5b), and perfection of the L-ring results in 5c.



Chemotaxis refers to an attraction or repulsion to chemicals in the environment. It is an ancient module found in bacteria, archaea, and eukaryotes. The proteins involved are termed *Che* (A, C, Y, Y-P and others). The final step in the process is the formation of the C-ring from the binding of a mutant proto-FliN, a CheC-like receptor, to FliG.



6. Flagellum

This produces the final product—a chemotactic flagellum (6). I have spent a lot of time on the evolution of the bacterial flagellum because it is the centerpiece of the Intelligent Design argument that some structures are so irreducibly complex that a supernatural designer had to be involved. The essence of Behe's ID argument is the question, "How could flagella have evolved?" The Matzke model provides a reasonable explanation of how this could have occurred. *The bacterial flagellum is reducible and it is modular.* Darwin was right when he suggested that cooption would play an important role in the evolution of complex structures. *The widespread cooption of pre-existing modules is how the flagella evolved by natural selection.*

Despite the great complexity of the bacterial flagella, the Matzke model shows that it is both reducible and highly modular. Darwin was right when he suggested that cooption of previously existing structures and functions would play an important role in the evolution of complex structures. Widespread cooption is how the flagella evolved by natural selection.

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Chapter 14

Evolution Now: Introduction

A very common complaint of both creationists and Intelligent Designers is that man has not been able to observe evolution actually occurring. It is all something that happened in the past and thus is only hypothetical. The Creationists are all from Missouri—"show me evolution occurring 'now' or I don't believe it ever happened." By "now," I will assume this refers to the time that scientific records have been kept, or about the past 200 years. This could be referred to an "observable evolution," or "evolution in our time," or "recent evolution." In the following chapter titles I will refer to it as "Evolution Now."

Definition of a *darwin*

Because part of this issue concerns the rate of evolution, it raises the question of how to quantify the rate of evolution. In 1949 the geneticist J. B. S. Haldane[1] proposed a unit of evolution called the *darwin.* He sought to quantify the rate of changes in body form, such as size, over time. To allow the unit to be applied to animals of all sizes instead of referring to absolute size as in centimeters or feet, he used percent change and chose a change of one percent as his unit for size. Since geologic and evolutionary time periods are large, he chose one million years for time. Thus a *darwin* referred to a one percent change in some measurement over one million years. Haldane realized that the rate of change that animal breeders could produce was much higher than one *darwin.* However, Haldane meant this to be a measure of evolution as it occurs in nature. When evolution in nature is determined from fossil records, most organisms evolved at a rate of less than one *darwin.* In subsequent chapters, you will see that when examined carefully, some organisms evolve in nature several thousand times faster than that.

The first "Evolution Now" chapter recounts the story of one of the most famous examples of evolution now—Industrial Melanism and the Peppered Moth.

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Chapter 15

Evolution Now: The Peppered Moth and Industrial Melanism

By the time of the mid-1800s the Industrial Revolution in England was in full bloom. In the days long before the Clean Air Acts, cities like Manchester, England became filled with dirty dust and soot.

> The sky resembled no sky on Earth so much as some Victorian vision of hell; dark even at noon, with roiling plumes of black smoke. So foul was the Manchester air in 1848, at the height of the Industrial Revolution, that mothers, it was said, could barely make out the outlines of their children across the street. [1p16]

As much as 50 tons of industrial fallout settled over each square mile of the city every year. The trees, houses, and every other surface around Manchester and the other dark mill towns were coated with black soot. The pollutants ran down the tree branches in rivulets, destroying the lichens that grew on the bark. Soon all the tree trunks were stripped of lichens. [1p17] The Peppered moth, *Biston betularia,* f. *typica,* sometimes called *Amphidasys betularia,* had a range that spread throughout England. The last part of its name, *typica*, refers to the variety or sub-species.

Figure 1. The Peppered moth, Biston betularia, *F.* typica. *From Coyne, J.:* Nature. *418:19, 2002.* [2] *By permission.*

In 1848, R. Edleston, an amateur moth collector living in Manchester, caught a rare dark, or melanic, form of the Peppered moth (Figure 2).

Figure 2. The Peppered moth, Biston betularia, F. carbonaria. From Coyne, J.: Nature 418:19, 2002 2 By permission.

He called it *Biston betularia,* F. *carbonaria.* In the latter half of the nineteenth century this black form spread rapidly throughout England. Edleston finally published his find in 1864.[3] By that time there were so many of the *carbonaria* that he wrote, "If this goes on for a few years the original type of *B. betularia* will be extinct in this locality." In fact, by 1895 the *carbonaria* form had reached a frequency of 98 percent in Manchester, and in many other places it had all but replaced the *typica* form. The Peppered moth produces only one generation a year. Thus, *to have virtually replaced the typica form in fewer than 50 years represents an astonishingly rapid change.*

The first person to suggest this rapid change was due to natural selection was J.W. Tutt. In 1896[4] he proposed that the *typica* form was protected from predators by mimicking the lichens on tree trunks. He proposed that in industrial regions where the lichens had been destroyed by pollution and the tree trunks blackened by soot, the *typica* forms lost their protective mimicry and were rapidly eaten by birds. By contrast, the *carbonaria* forms flourished because now they were the ones that were hard to see against the black tree trunks. Since the melanism was due to a genetic mutation, the survivors passed this protection on to their offspring.

In some areas there was an intermediate form. These were called *insularia.* All three forms were due to multiple alleles at a single genetic locus.[5] The *carbonaria* form was dominant to the *insularia* and *typica* forms. This has been verified in studies of over 12 thousand progeny from 83 families.[6]

This was how the story of the Peppered moth and industrial melanism stood at the turn of the century and for the following 50 years. It was a beautiful, even fantastic, example of evolution in action. A dramatic change in the environment resulted in the selection of a rare new or preexisting genetic variant that was now better suited for survival and rapidly became more common in the population. Breeding studies showed it was an inherited genetic change, just as Darwin predicted.

One of the constant complaints of creationists was that the theory of evolution was flawed because one could not see it happening "in our time." They were not deterred when evolutionists explained that evolution occurred gradually and took a

long time. The creationists kept saying, "If you can't show me, it does not exist." *Biston betularia,* F. *carbonaria* and industrial melanism allowed evolutionists to "show them" the striking rapidity with which natural selection could operate. *Evolution was real and was occurring both in real time and in our time.*

The brilliant Oxford geneticist John Burdon Sanderson Haldane further enhanced the melanism story. In 1924 he published a paper on the evolutionary genetics of the Peppered moth.[7] Based on the takeover of the *carbonaria* form in fewer than 50 years, Haldane calculated that for this to have occurred so rapidly it would require a selective advantage of 50 percent. Recall that prior to this Fisher had calculated that a selective advantage of only one percent was sufficient to fuel significant evolutionary change. Here was a selective advantage of 50 times that.

This raised a question that would take another 30 years to answer. What was the mechanism of this rapid selection? Was the lichen-centered mechanism the answer? Around the time that Haldane published his remarkable paper, Fisher had just met a fellow dedicated Darwinist, Edmund Brisco Ford. They both dreamed of a way of studying evolution not in the laboratory, but in nature, that was experimental, rigorous, and above all, quantitative.[1p53]

By 1937 E.B. Ford was a geneticist on the Oxford faculty. Bernard Kettlewell was a medical doctor working as a general practitioner in Cranleigh, Surrey, south of London. He was a passionate collector of butterflies and moths. On a collecting trip to the Black Wood of Rannock, in the Scottish Highlands, he met Ford who was there with a friend seeking a rare species of butterfly.[1p69] This chance meeting blossomed into a long, although somewhat tumultuous, friendship.

In 1951 E.B. Ford received a grant for studies in the field he had created, Ecological Genetics. He turned to his old friend Bernard Kettlewell to carry out the kind of studies he and Fisher had dreamed of years before. Kettlewell's objectives included direct observations of birds eating moths placed onto tree trunks and the marking of *typica* and *carbonaria* moths with a small spot of paint, releasing them and, after one to two days, recapturing them. They were then released onto trees in polluted and unpolluted woodlands.

The observation of birds preferentially eating moths depending upon their color and background was actually filmed in cooperation with Niko Tinbergen, a world-famous Oxford animal behavioralist. For example, in one filmed session involving nonpolluted trees, Tinbergen observed a spotted flycatcher eat 46 black moths and only eight typicals. The conclusion was that conspicuous insects were more vulnerable to predation than inconspicuous insects. Figure 3 shows the *typica* and *carbonaria* types on polluted and lichen covered trees.

The mark-release-recapture results were impressive. In the first such experiment, done in a polluted Birmingham woodland, of 447 melanics released, Kettlewell recaptured 123, or 27.5 percent. Of the 137 typicals released he recaptured only 18, or 13.0 percent, a 2-to-1 ratio of melanics to typicals. Two years later he performed the reciprocal experiment in an unpolluted woodland in Dorset. Of 496 typicals released he recaptured 62, or 12.5 percent, but of 473 melanics release he recaptured

Figure 3. Left. Carbonaria *(top) and* typica *(bottom) Peppered moths on polluted tree trunks.* Right. Typica *(top) and* ***carbonaria*** *(bottom) Peppered moths on nonpolluted lichen-covered tree trunks. The* carbonaria *form on the left and the* typica *form on the right were so hard to see they have been marked with a red arrow. These are posed pictures.*

only 30, or 6.3 percent, a 2-to-1 ratio of typicals to melanics in a reverse direction compared to the prior experiment.[8,9] He summarized his findings in a famous 1959 paper in *Scientific American* entitled "Darwin's Missing Evidence."[10]

The enactment of clean air acts in England and the United States further enhanced the Peppered moth story. In England these acts began to be implemented in 1956. By the 1980s three different surveys documented an extraordinarily rapid decline in the frequency of the *carbonaria* form, from over 90 percent to 40 percent. By 1994 in one survey it had decreased to 20 percent.[11] With comparable industrial polution there was a similar increase in the frequency of melanic forms of the Peppered moth in the United States. In an area near Detroit it had increased from zero to 90 percent. With the passage of clean air acts in 1963 the frequency of melanic forms in the same areas also dropped to 20 percent by 1995.[1p16]

Kettlewell's studies of industrial melanism rapidly became the poster boy for providing proof of Darwin's theory of evolution. The pictures in Figure 3 and others have been reproduced in countless textbooks of biology. The beauty of the Peppered moth story is that it is so easy to both see and to understand. One could not possibly dream up a better example and proof of the correctness of Darwinian evolution and natural selection. Or could they?

Attacks on the Peppered Moth Story

An attack on the Peppered moth story was launched largely with the help of Kettlewell's own scientific colleagues. While the creationists and Intelligent Designers have carried the banner, waved the anti-evolution flags and beat the drums, in fact,

all they really had to do was sit back and pick up the pieces, with great glee. They pounced on this scientific debate with the same fervor that they pounced on "punctuated equilibria" when they overinterpreted the scientific debate and claimed that Eldridge and Gould had disproved Darwinism. The following are some of the slings and arrows that were unleashed. I will start with what Jonathan Wells said in his chapter on Peppered Moths in his anti-evolution book, *Icons of Evolution.* [12]

- *Imperfect correlation with pollution.* On both the upswing and the downswing, after the clean air acts there was not a precise match between the frequency of the *carbonaria* form and areas that were or were not polluted.
- *The exaggerated role of lichens.* The primary reason for suggesting that the *typica* form survived in nonpolluted areas was because they mimicked the presence of lichens on the trees. When the *typica* form increased in frequency after the Clean Air Acts were enacted, they did so before lichens returned to the trees. The same thing happened in the Unites States. The *typica* form increased without changes in lichen cover.
- *Peppered moths don't rest on trees.* Kettlewell placed all of his moths on tree trunks. However, Cyril Clarke, who was also an avid collector of Peppered moths, stated that in his many years of field work he had only seen the Peppered moth on a tree trunk once. The Peppered moth is nocturnal. During the day, they stay on the underside of leaves, not out in the open on tree trunks.
- *The Peppered moth pictures were staged.* Based on the positioning of the antennae and other aspects of the moths, it was clear that in some of the pictures the moths were dead and these photos were staged. In other pictures the moths were alive, but still staged.
- *Birds and UV vision.* While the studies of Kettlewell utilized evaluations based on human vision, birds use the ultraviolet spectrum in their vision. Thus, they may see past what looks like camouflage to human eyes.
- *Jerry Coyne's Santa Claus comment.* In the November 5, 1998 issue of Nature, [2] Jerry Coyne, a professor of ecology and evolution at the University of Chicago, reviewed a book by Michael E.N. Majerus entitled *Melanism: Evolution in Action.* [13] In the book, Majerus listed a range of criticisms of Kettlewell's studies. These included such things as A.) the moths do not usually rest on tree trunks, B.) bird vision is different than human vision, C.) the high densities of moth placement may have skewed the results, D.) problems with the timing of release, and others. Despite all his criticisms, Majerus still believed that Kettlewell's conclusions about the mechanism of natural selection were valid. Majerus stated, "My view of the rise and fall of the melanic Peppered moth is that differential bird predation in more or less polluted regions, together with migration, are primarily responsible, almost to the exclusion of other factors."

  Jerry Coyne, however, was "horrified." [1p283] He had been teaching the standard version of the Peppered moth for years. He concluded, "we must discard *Biston* as a well-understood example of natural selection in action, although it is

clearly a case of evolution." He capped off his comments with the statement, "My own reaction resembles the dismay attending my discovery, at the age of six, that it was my father and not Santa who brought the presents on Christmas eve." Talk about fodder for the creationist's anti-evolution diatribes. This was music to their ears. Here a member of the evolution establishment was trashing one of its own icons of evolution.

- *Hints of fraud.* To make matters worse, in her generally delightful book entitled, *Of Moths and Men,* Judith Hooper even implies that Kettlewell fudged his results. This was based in part on that fact that Kettlewell wrote to Ford about some initial disappointing recapture results. Hooper stated:

> We don't know exactly what state Bernard [Kettlewell] was in, but we can deduce something of it from a letter dated 1 July from Henry [Ford], who wrote, "It is disappointing that the recoveries are not better…However, I do not doubt that the results will be very well worth while." The message sounds benign enough, but knowing Henry, Bernard might have decided it to mean, "Now I do hope you will get hold of yourself and deliver up some decent numbers." He now felt that his fate as a scientist was hanging on this experiment. [1p114-115]

Hooper notes that the percent of recaptures immediately and dramatically increased after Kettlelwell got the note from Ford. Based on these problems, Wells gleefully termed the Peppered Moth study "the Peppered Myth."

Defense Against the Attacks

Are these criticisms fatal or are they simply the normal critical examination of studies by colleagues that takes place all the time and contributes to the power of science to find the truth? I will examine each issue.

The imperfect correlation with pollution. In general the correlation between the frequencies of the *carbonaria* form and the presence of pollution was quite high. However, it was not perfect. Unlike the pictures, the moths are not glued to the trees. They fly around and migrate from place to place.

The exaggerated role of lichens. In 1996 Sir Cyril Clarke, Grant and Owen wrote:

> The changes in allele frequencies in the moth populations we sampled occurred in the absence of perceptible changes in lichen floras. We suggest that the role of lichens has been inappropriately emphasized in chronicles about the evolution of melanism in peppered moths. [14]

However, they did not just leave the mechanism of selection hanging. They added that regional reductions in the soot component of atmospheric pollution meant that the surface reflectance from tree bark, even in the absence of lichens, would be lighter. [14,15] Grant and Howlett [16] also suggested that well-documented

increases in the abundance of silver birch trees following the establishment of "smokeless zones" also changed the habitat.

In both Britain and the United States, the frequencies of the *carbonaria* form closely paralleled the increase and decrease in the levels of atmospheric sulfur dioxide.[14] It had been assumed that sulfur dioxide was killing the lichens and this affected the relative predation by birds. The observation by Clarke and colleagues that the increases and decreases in *carbonaria* frequency could occur in the absence of changes in lichens suggested the sulfur dioxide could work through a mechanism that was independent of bird predation. This work was covered in *The New York Times* with the statement, "While it is unclear exactly how natural selection is acting, it is very clear that selection is hard at work."[17]

Majerus[13] was not convinced and felt the Clarke report was not sufficiently detailed to make this sweeping generalization. In addition, a report by Cook[18] found that after the clean air act there was an increase in lichens in the most polluted areas, and this was reflected in an increase in the *typica* form.

As in most scientific quarrels, it is likely that both sides have a part of the truth. Lichens and bird predation were a factor, but not the only factor, leading to the changes in the frequency of the *carbonaria* form of the Peppered moth. However, both bird predation and the other factors acted through the mechanism of natural selection.

Peppered moths don't rest on trees. Peppered moths are nocturnal, and during the day they hide under the leaves, not on the tree trunks. Despite this, the above conclusion that bird predation and other factors cause differences in natural selection of the *carbonaria* and *typica* forms is still valid. In addition, recall the description of the level of pollution, at the beginning of this chapter. The soot and dirt were everywhere, providing plenty of places other than tree trunks for a *carbonaria* form to hide from birds.

Peppered moth pictures were staged. Given the difficulty of finding a *typica* and a *carbonaria* moth conveniently sitting next to each other on both a blackened tree trunk and a lichen-covered tree trunk, it is not surprising that Kettlewell placed living or dead moths on representative pieces of tree trunk simply to illustrate to the reader what he felt was the mechanism of the natural selection. As the above comments illustrate, the real story was not that straightforward. The staging of the tree trunk pictures does not change the real picture of a dramatic increase in the *carbonaria* form in polluted areas and the dramatic increase in the *typica* form when the pollution was eliminated, and of the replication of this pattern on two continents.

Birds and UV vision. Later research has shown that the moths are camouflaged in ultraviolet as well as in visible light.[19,20]

Jerry Coyne's Santa Claus comment. Despite his Santa Claus comments, in a review of Hooper's book, Coyne[2] strongly defends Kettlewell. Coyne refered to a colleague who described Kettlewell as "the best naturalist I have ever met, and almost the worst professional scientist I have ever known." As to Ford's letter he states, "This sounds familiar; many of us have offered similar consolation to students having a hard time in the field." As with Young and Musgrave (see next page) Coyne attributes the

sudden increase in recapture rate on July 1 to a marked increase in the number of moths released, not to fraud. And yes, there were some problems with the study design, "but sloppiness is not fraud." Coyne suggests that Hooper unfairly smeared a brilliant naturalist.

Hints of fraud. Hooper [1] suggested that the sudden increase in moth recapture rate on July 1, the day Ford sent his letter "of encouragement," does not pass the fraud smell test. Young and Musgrave [20] presented a detailed response to this charge. They point out that from June 25 to 29 Kettlewell released an average of 31 moths per day and recovered (with a one-day delay) an average of 4.4 moths per day. On June 30 he released 102 moths, and on the morning of July 1, before he could have gotten Ford's letter, he released 114 moths. This resulted in an average recapture rate of 28.5 per day. On further analysis of the entire recapture experiment, Young and Musgrave showed there was a very high correlation ($r = .80$) between the number of moths released and the number recaptured. Thus, an increased release rate rather than fudging data in response to Ford's letter accounted for the jump in recapture rate. As further evidence of the validity of Kettlewell's findings, Majerus [12] reviewed five other subsequent studies, using modified experimental designs, that corroborated the fitness differences between carbonaria and typica in polluted and unpolluted regions.

In summary, no scientific study is perfect. As a scientist who has sat on many NIH study sections, reviewed hundreds of manuscripts, and had my own papers reviewed, I can say with confidence that virtually every study, every paper, and every grant receives its healthy share of criticism, with a special emphasis on methodology. A truism is, "If you don't like the conclusions, attack the methods." But that is the power of science. No scientist is immune from having their work very carefully examined. Sometimes the process is so contentious that good studies don't get published and many more don't get funded. When all of the difficulties of the type of study Kettlewell carried out are examined, it is questionable whether anyone could produce a study that could not be criticized. Despite all the criticisms the current state of the Peppered moth as an "icon of evolution" is well summarized by Grant. [21]

> The similarity of patterns between the British Isles and North America indicate parallel evolutionary changes that cannot be explained by anything other than selection acting independently on similar phenotypes in widely separated populations of the same species. On both continents, high frequencies of melanism and subsequent reductions correlate well to the same key factor: atmospheric pollution from regional industrial development and urbanization. No other evolutionary force can explain the direction, velocity, and the magnitude of the changes except natural selection. Certainly there are other examples of natural selection. Our field would be in mighty bad shape if there weren't. Industrial melanism in Peppered moths remains one of the best documented and easiest to understand.

Contrary to Jonathan Wells's characterization of the Peppered moth as "the Peppered Myth," with qualifications, the Peppered moth and industrial melanism still deserve to be in textbooks as classical examples of natural selection and of evolution in action and in our time.

The dramatic and rapid increase in the frequency of the black or melanic form of the Peppered moth in areas of England and the United States most severely affected by industrial pollution, and the equally dramatic decrease in the frequency of the blackened form after Clean Air Acts decreased the soot and sulfur dioxide in the atmosphere, is a classic example of natural selection. To attempt to determine the mechanism of selection, Bernard Kettlewell performed a series of experiments consisting of marking both forms of the moth, releasing, and later recapturing the survivors. He found that in polluted areas where the tree trunks and everything else were blackened, birds had difficulty seeing the black form and more of them survived. In nonpolluted areas, where the tree trunks were white due to lichens, birds had difficulty seeing the whiter form of the moth and more of them survived. This has been touted in textbooks as a classic example of natural selection.

Since these experiments, there have been many criticisms of Kettlewell's methods and of the basic hypothesis on which the study was based. As shown in the above discussion, it is clear that while some of these criticisms are valid, some are not. Despite this, industrial melanism as exemplified by the Peppered moth remains a powerful example of natural selection and of evolution in action and in our time.

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…the more you look, the more you see

Peter Grant
Ecology and Evolution of Darwin's Finches

Chapter 16

Evolution Now: Darwin's Finches

It is a common misconception that Darwin first formulated his theory of evolution when the H. M. S. Beagle brought him to the Galapagos Islands where he noticed that the beaks of the finches were different on each island. He thought, as the myth goes, that a divine creator would have made a single species for all islands and that evolution involving natural selection would have fashioned each bird to match the type of seeds and the environment unique to each island.

Nothing could be further from the truth. In actuality, Darwin misclassified most the finches he collected as blackbirds, wrens and warblers and did not even bother to note which island they came from. [1,2] He thought they all represented species from the mainland of South America. He only noted the islands of origin for the mockingbirds he collected.

In his Pulitzer Prize-winning book, *The Beak of the Finch,* Weiner [3p27] notes that Darwin's earliest thoughts relevant to evolution came on the voyage home. In his notes he states that the mockingbirds on two of the islands seemed unique to those islands. He thought they were only varieties, but then wondered—"What if there were no limits to their divergence? What if they had diverged first into varieties, and then gone right on diverging into species, each marooned on his own island." As Weiner recounts,

> Darwin wrote, "the zoology of Archipelagoes—will be well worth examining, for these facts undermine the stability of Species." Then, in a scribble that foreshadowed two decades of agonized caution, Darwin inserted, "[this] would undermine the stability of Species."

On January 4, 1837, two months after the Beagle docked in Falmouth, England, Darwin gifted his bird collection to the Zoological Society of London. Immediately after examining these study skins, the ornithologist John Gould announced that they consisted of 14 new species that were unique to the Galapagos. [3p28] In addition, Gould also noted that the mockingbirds Darwin brought home were different depending upon the island from which they originated.

To determine if the finches also showed island-to-island variations, Darwin had to ask Fitzroy, the captain of the Beagle, if he could examine the birds Fitzroy and other shipmates had collected and labeled by the island of origin. While Darwin described the finches in his initial draft of *The Origin of Species,* he did not mention them in the final version, possibly because of the haphazard way he had handled the labeling of the specimens. Thus, mockingbirds, not finches, played the major role in the beginnings of Darwin's thinking about the origin of the species.

The following passage from his memoirs of *The Voyage of the Beagle,* written years later, probably contributed to the myth,

> In the thirteen species of ground-finches, a nearly perfect gradation may be traced, from a beak extraordinarily thick, to one so fine, that it may be compared to that of a warbler. I very much suspect, that certain members of the series are confined to different islands…

Despite this imperfect record, the finches of the Galapagos are now known as "Darwin's finches."

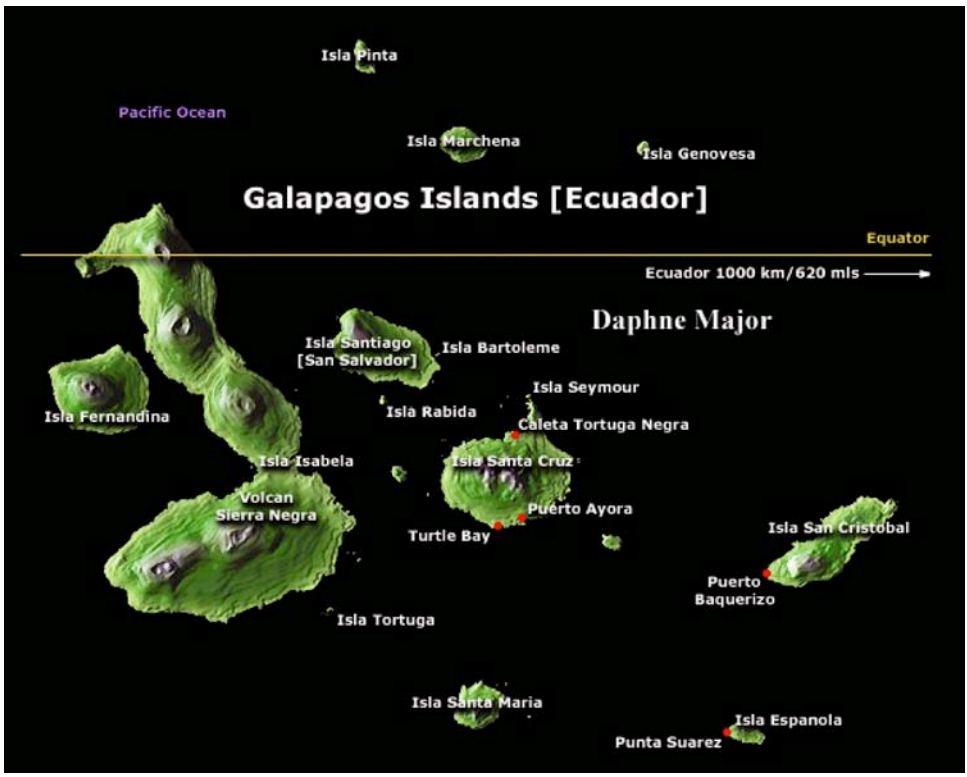

Figure 1. The Galapagos archipelago. The tiny island of Daphne Major is north of Santa Cruz island.[4] *Courtesy of Mountain High Maps, Bugbog.com.*

Studies by the Grants

Peter and Rosemary Grant studied Darwin's finches on Daphne Major, one of the smallest islands of the Galapagos archipelago (see Figure 1). Their studies lasted continuously from 1973 into the twenty-first century, the longest period of time ever recorded for such work. They have produced the most detailed record of evolution in action ever compiled. The results, eloquently related in Weiner's book, [3] have *enormous relevance to the understanding of many of the most fundamental aspects of evolution.*

The small size and remoteness of this uninhabitable island allowed the Grants to record a vast array of variables about the birds and their environment over the months they were on the island, without concern that things would be disturbed when they were not there. These variables included measures of the length, width, and depth of the birds' beaks; body weight, wing span; all of the species of plants; the size of all the seeds on the island; the amount of pressure required to break open the seeds; which birds ate which seeds; who mated with whom; who was left out of the mating game; how many progeny each bird had; who their parents, grandparents, and great-grandparents were; when each bird died; and many other important facts. Darwin's ground finches, from a drawing by the Grants' daughter Thalia, are shown in Figure 2.

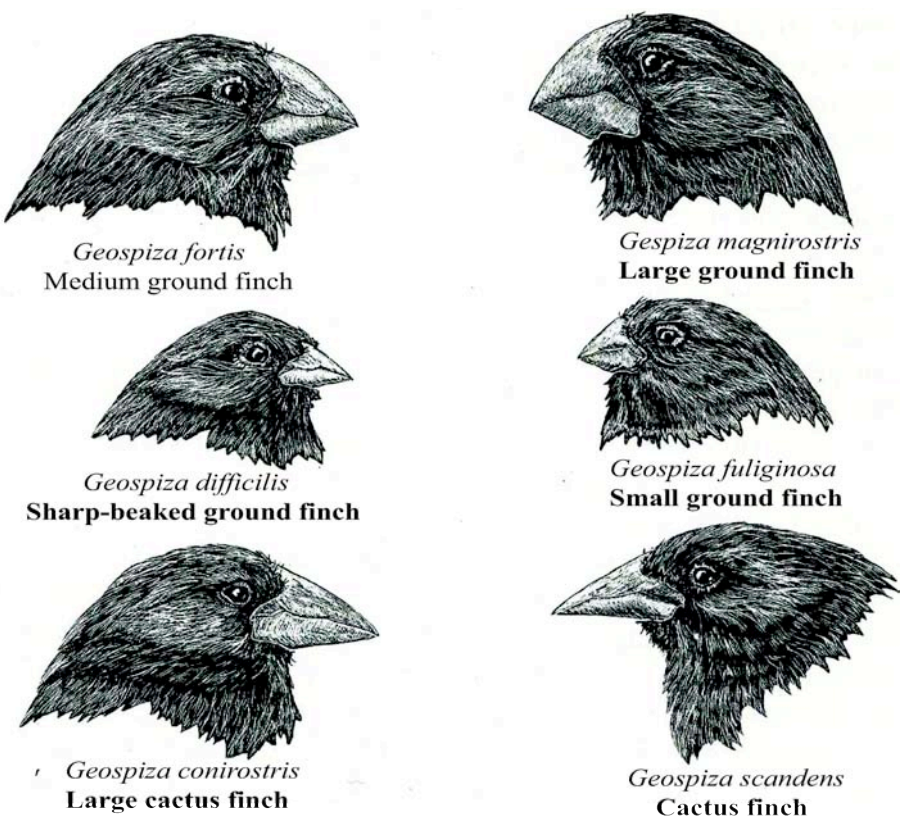

Figure 2. Darwin's ground finches drawn by Thalia Grant. From Jonathan Weiner, The Beak of the Finch. [3]

A pair of male (dark) and female (brown) finches in color are shown in figure 3.

Figure 3. A pair of Darwin's finches from The Zoology of the Voyage of H.M.S. Beagle, Under the Command of Captain Fitzroy During the Years 1832 to 1836. [5]

The Drought

For the first several years of the Grant's data collection, not much happened. Then in 1977 there occurred one of the worst droughts ever recorded on the Galapagos. Figure 4 shows the changes this wrought on *Geospiza fortis.*

There was a dramatic decrease in the number of birds, with males dropping from 600 to 150 and females dropping from 600 to 25. The survivors were 6 percent larger than before the drought. The length of the bill increased from 10.68 to 11.07mm and the depth of the bill increased from 9.42 to 9.96 mm, when the birds before the drought were compared to the drought survivors. While an increase in the depth of the bill of only .54 mm may seem miniscule, it is a 5.7 percent change. As with the Peppered moth, this was one of the most intense episodes of natural selection ever recorded in nature.

These careful measurements showed that in the drought, when only the largest and most difficult seeds to break were available, the larger birds with the longest and thickest beaks were the ones to survive. This change, so small it is hard to appreciate by the naked eye, made the difference between life and death for the finches.

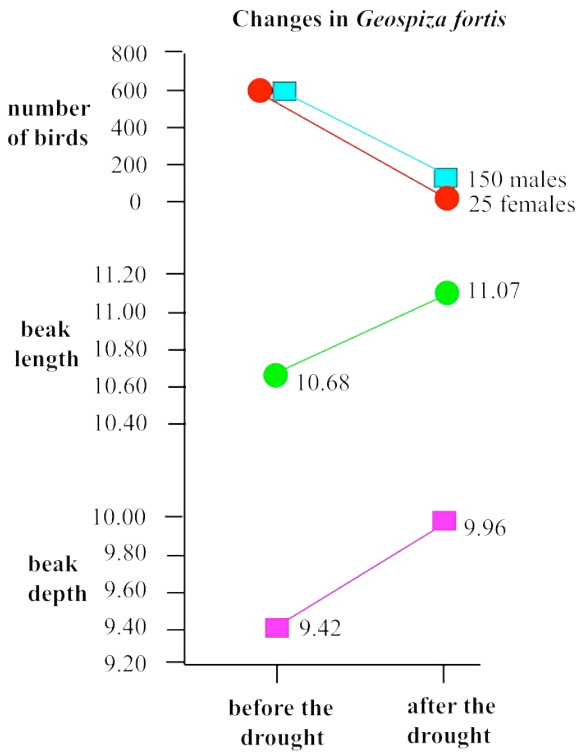

Figure 4. Changes in Geospiza fortis *following a severe drought on Daphne.*

As Peter Grant stated, natural selection takes place within a generation while evolution takes place across generations. Figure 1 shows the results of natural selection. Because data was also collected on mating, breeding, and offspring, it was also possible to study evolution. This also held some surprises. Because there were plenty of males but only a few females, each male had only a one in six chance of passing on its genes.

Remarkably, the females seemed to sense the crisis and only picked as partners birds that were the blackest, had the most mature plumage, were the largest, and had the largest beaks. Most of the males were left out of the mating game while every single female mated. Since the surviving females were also the largest, this, plus the choice by the females of the largest males, contributed to a 5 percent deeper bill in the next generation. This was evolution in action, resulting in larger, stronger birds with deeper bills—better equipped to open the largest seeds.

A statistical analysis showed selection was the strongest for body size and depth of beak. There was no selection for the length or width of the beak. Peter Grant wrote, "a narrow yet deep bill was the best instrument for performing the difficult task of tearing, twisting, and biting the mericarps [seed covering] of the *Tribulus*

[plant] to expose the seeds."

This study proved Darwin correct when he proposed that evolution works by the natural selection of genetic variations that cause small changes but provide greater fitness and are passed on to subsequent generations. He undoubtedly would have been surprised by the incredible speed of the rate of these changes. More on this later.

The results of the Grants' study raised a number of intriguing questions. First, why didn't evolution just keep producing larger and larger birds who were better and better at uncovering the *Tribulus* seeds? It also raised the question of why evolution, as measured in the fossil record, progressed at less than 1 *darwin* per million years, while *G. fortis* posted a rate of 25,000 *darwins*? One could argue that this rate jumped because of extreme environmental stress, but surely there would be many comparable stresses over a period of a million years. These should be compounded to push the number of darwins to still higher levels. The answer came quickly.

The Flood

In 1982 the weather on Daphne went to the opposite extreme. December of that year saw rains that were greater than any since the founding of the Charles Darwin Research Station in 1960. The plant life was going from desert to jungle. One of the research team said, "The birds went crazy. The year before there had been no breeding at all. Now they bred like hell." [3p101] Females produced up to 40 eggs and up to 25 offspring per bird. One female went through four males, one after the other.

There were now ten times as many small seeds on the ground and big birds with big beaks had trouble feeding on the small seeds. An analysis of the data after the flood showed that now selection was reversed. Big birds with big beaks were dying while small birds with small beaks were surviving. Since they were larger they had to eat more seeds to stay alive. [3p105] In addition, males were dying at a faster rate than females. Thus, in flood conditions everything was the reverse of the selection that occurred in drought conditions.

The finding that drought pushed evolution in one direction while floods pushed it in the opposite direction provides us with great insight into several apparent problems in evolution. When examined over longer periods of time, organisms appear to evolve very slowly at a fraction of a *darwin.* However, the closer the observer examines life the more rapid the evolution, in some cases reaching over 60,000 *darwins.* The reason evolution appears to move so slowly over long periods of time is now clear—*the rapid oscillations cancel each other out.*

This could also explain both the punctuations and the equilibria of punctuated equilibria. The punctuations would occur when severe environmental stress accelerated variation and then speciation. Equilibria would occur when environmental stresses were balanced, thus resulting in balancing of the short-term but large evolutionary changes into long-term minor evolutionary changes.

Principle of Divergence

While competition among species is at the heart of Darwin's Theory of Evolution, he also proposed a *Principle of Divergence.* Here he predicted the general absence of competition. He proposed that in a large group of organisms all competing for the same food, variants might be different enough that they would occupy different habitats and thus significantly reduce competition. This would result in adaptive radiation (Figure 5).

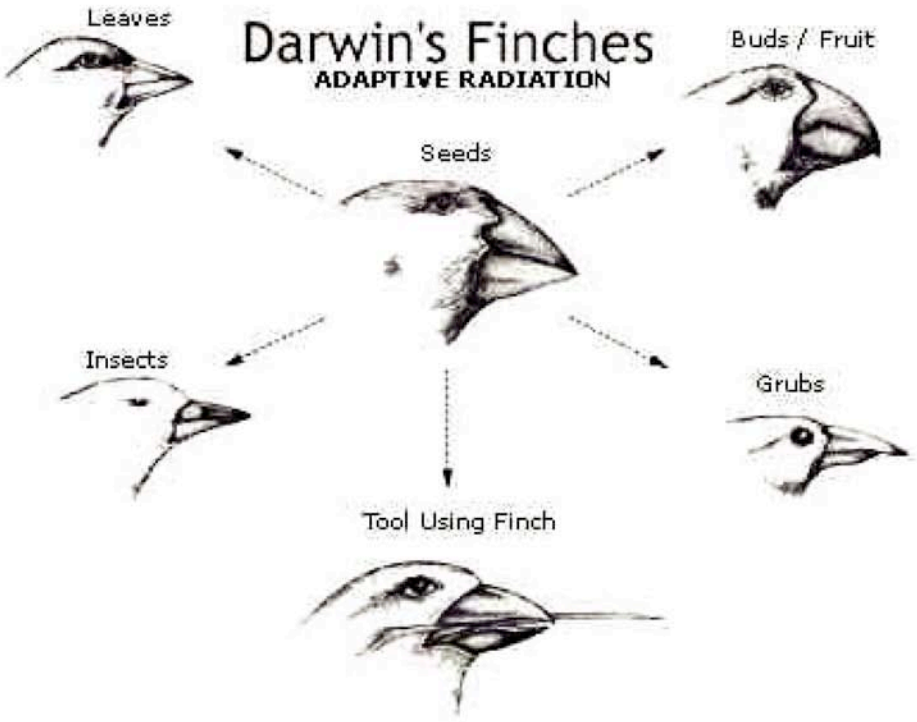

Figure 5. The principle of adaptive radiation with the evolution of different beaks suited to different environmental conditions.

In 1947 David Lack published a book entitled *Darwin's Finches.* [6] He found that in low-lying islands without mountains, either *G. fuliginosa* with small beaks or *G. difficilis* with sharp beaks were present, but never both. Here the competition was so great only one species survived. However, in islands with mountains, both species were present, but they occupied different ecological niches. The *G. fuliginosa* occupied the base of the mountain while the *G. difficilis* were near the top.

This supported Darwin's *Principle of Divergence,* or competitive exclusion. By adopting two different habitats, the two species could exist on the same island without competing with each other. Animals may evolve such that their physical characteristics are sufficiently different to allow them to occupy these different ecological niches, and thus escape from deadly competition. This is called *character displacement.*

Speciation by Hybridization

The Grants found that mating between species was rare, and under usual environmental circumstances the offspring of hybrids did not survive. However, following the flood, the competition for food was relaxed sufficiently for the offspring of those rare hybrids to survive. Hybridization between two related species has the advantage that it increases the range of genetic variation in an individual. Greater genetic variation increases the potential to survive dramatic changes in the environment. The Grants pointed out that while rare, this was another tool to facilitate speciation.

Death Knell to Anti-Evolutionists

These studies of the finches of the Galapagos rang a death knell to the many complaints of the Creationists. These studies showed that evolution is an ongoing process and that it occurs now and in our time. They explain why some species remain static over long periods of time while some rapidly diversify. Thus they explain both the punctuation and the equilibria of punctuated equilibria. They explain speciation by geographical separation (allopatric speciation) and evolution without geographic separation (sympatric speciation). They illustrate the intimate and often reciprocal interaction between animals and their environment. They validate Darwin's *Principle of Divergence*, competitive exclusion and character displacement by which species can actually escape from competition. They explain why the rate of evolution is often a fraction of a *darwin* when the fossil record is examined, but can be as high as 60,000 *darwins* when the interaction of a species with extreme environmental changes is examined over short periods of time. These studies falsify the claim that there is not enough time for evolution to occur.

The Creationists' Anti-Evolutionary Spin

In view of the above I was astonished to see Darwin's Finches and Weiner's book on the Grant's work mentioned in Jonathan Wells's anti-evolution book *Icons of Evolution.*[7] I would think that the last thing the creationists would want to do would be to call attention to this marvelous body of work. What possible spin could they come up with to claim this was evidence against evolution? The following is what Wells did.

First, rather than simply taking note of the interesting historical fact that Darwin was not that invested in the finches that were named after him, Wells treats this fact as some sort of conspiracy by evolutionists to mislead the public. In scientific studies, the record about who really discovered what gets corrected all the time without affecting the validity of the basic facts.

Second, Wells then attacks the beautiful studies of the Grants by saying that they did not actually observe speciation occurring and implied that the increase in beak size brought about by the drought would always be reversed by periods of flooding.

Finally, he attacked the Grants' studies on hybrids by claiming they prove that species fusion by hybridization is more common than species diversification. This

ignored the statement by the Grants that cross-species hybridization is a rare event. The fact that over the lifetime of the earth over one billion species have evolved further indicates the absurdity of this claim.

The beauty of the finch studies is that they were field studies of actual evolution in action. They illustrated the mechanisms by which evolution occurs and illustrated the rapidity by which those changes can take place. The existence of many different ice ages; of continental shifts with the formation of mountains where sea bottoms once were and sea bottoms where mountains once were; the transformation of jungles into deserts and deserts into jungles; the occurrence of major climate change due to asteroids impacting the earth; and many other forces of nature have produced prolonged and lasting changes in both local and world-wide environments. The presence of these forces illustrated that in many cases the environmental changes continue in only one direction rather than undergoing short balancing cycles.

The Grants were observing the equilibrium part of punctuated equilibria. Punctuations resulting in new species are rarer. For a given trait, species tend to differ by 15 percent or more. If a single season of adverse climate were able to produce a 5.7 percent change, it would not require more than three or four successive seasons of the same type of adversity to result in a new species.

Now that we have observed the mechanism of evolution in action, it requires only a trivial amount of thinking to understand that when the environmental changes are unidirectional, new species and new punctuations can occur quite rapidly. Wells's slavish dedication to creationism seems to prevent him from this line of thinking. Strong support for the importance of climate in evolution is provided by detailed studies of 80,000 mammal fossils in three regions in Spain, covering a period of 22 million years. [9] Climate changes were assessed by geological and astronomical records. These studies showed that the evolution of new species was driven more by long-term climate changes than by competetion between species.

Studies of the finches of the Galapagos ring a knell to the complaints of the creationists. These studies show that evolution is an ongoing process and that it occurs in our lifetime. They explain why some species remain static over long periods of time while some rapidly diversify. They explain both the punctuation and the equilibria of punctuated equilibria, and speciation both with and without geographical separation. They illustrate the intimate and often reciprocal interaction between animals and their environment. They explain why the rate of evolution is often very slow when the fossil record is examined, but can be very rapid when the interaction of a species with extreme environmental changes is examined over short periods of time. They especially falsify the claim that there is not enough time for evolution to occur.

Other Examples. The stories of the Peppered moth and Darwin's Finches are so effective in illustrating the concept that evolution is an ongoing process and is occurring now that additional examples are not necessary. However, for the interested reader, John Endler, in his 1986 book, *Natural Selection in the Wild,* [8] listed examples of natural selection in over 110 species, often with multiple examples per species.

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Chapter 17

The Evolution of Man

While the theory of evolution and the origin of the species was a troubling concept for many, especially theologians, the idea that man evolved from the apes was especially difficult to accept. In his *Icons of Evolution,* Intelligent Design creationist Jonathan Wells simply resorts to denial by suggesting that the descent of man from lower primates is simply a myth, by pointing out that the Piltdown Man, once considered one of the supposed "missing links," was later found to be a fraud, and by pointing out that Neanderthals were not really direct ancestors of man. [1p208-228] The latter two points are well-known truths in evolution science and have no relevance to the overriding fact that 99 percent of the DNA sequence of humans and chimpanzees is identical, a clear indication they are closely related species.

Another common tactic has been to simply ridicule the notion that man is a primate rather than address the science. This common approach is illustrated by the religious controversy that met the release of Darwin's *The Origin of Species,* which culminated in a debate between Thomas H. Huxley, an avid proponent of Darwinian evolution, and Bishop Wilberforce, the Bishop of Oxford, England. The bishop attempted to put away his debating opponent by asking which side of his family did he claim was descended from the monkeys. Huxley's famous rejoinder won the day:

> I would rather have a miserable ape for a grandfather than a man highly endowed by nature and possessed of great means and influence, and yet who employs these facilities and influence for the mere purpose of introducing ridicule into a grave scientific discussion.

Nonetheless, the pain many felt about being just one more animal and one more twig on the evolutionary tree, rather than the unique image of God created by God, persisted and has been one of the issues most fought over by creationists.

Twelve years after the publication of *The Origin of Species,* Darwin published *Descent of Man and Selection in Relation to Sex.* [2] There was very little fossil evidence at that time relevant to the descent of man. Instead Darwin listed a wide range of human features that had a similar structure and function in animals, including primates. In the section on the mind of man he stated the following:

> The differences in [the] mind between man and the higher animals, great as it is, certainly is one of degree and not of kind. We have seen that the senses and intuitions, the various emotions and faculties, such as love, memory, attention, curiosity, imitations, reason, etc., of which man boasts, may be found in an incipient, or even sometimes well-developed condition, in the lower animals.

Since Darwin's time a great deal more has been learned about the evolution of man. This remarkable journey is often considered to have entailed some of the following important steps: descent from the trees into the savannah or grasslands, walking upright, use of tools, development of speech and language, an increase in brain size, and the development of greater intelligence. The purpose of this chapter is to cover these aspects of human evolution. Since a main subject of this book is an examination of our analytical and spiritual brains, these aspects of human evolution will be examined in later chapters.

Lemurs — Our Earliest Ancestors

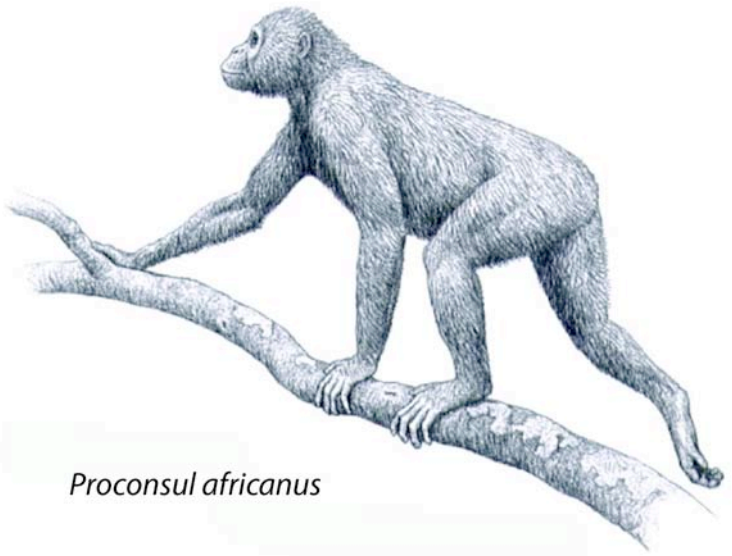
One of the earliest stages in the evolution of man involved the movement of the eyes from their usual position on either side of a large snout, as in the dog, to a more forward position. These early ancestors were the tree-living lemurs from the island of Madagascar and the tarsiers from Malaysia.

Figure 1. The lemur, a very early ancestor of man. [2a]

The advantage of forward-set eyes is that it provides improved three-dimensional vision, well suited for navigating without falling from the trees. The lemurs survived the K/T mass extinction that killed off the dinosaurs. We owe them a great debt for if they had not survived the devastation of the Yucatan comet, we would not be here. These small mammals with five strong fingers on each limb and a prehensile tail were the ancestors of other tree dwellers. To survive in the jungles of Africa, a larger and sturdier primate called *Proconsul africanus* (Figure 2) evolved. *Proconsul* thrived, spread throughout Africa and Asia and gave rise first to gibbons and orangutans, then to African gorillas and chimpanzees.

Descent to the Savannah and Bipedalism

About 6 million years ago a dramatic shift in climate occurred in Africa that lead to a decrease in the amount of land devoted to the jungles and forests and an increase in open savannahs. To survive the increasingly stringent struggle in the



Trudge, C. *The Variety of Life*, 2000

Figure 2. Proconsul africanus an ancestor to hominoid apes. [2b]

forests, our ancestors came out of the trees to occupy this expanding habitat in the Great Rift Valley. This resulted in the environmental stimulus to push the evolution of many new features. One of the most important was the shift to an upright posture with locomotion by walking on two legs (bipedalism). Numerous benefits of this have been suggested, including better vision in the tall grass, better access to food, better regulation of body temperature by exposing less surface to the African sun, [3] and freeing up the use of the hands for carrying food and children and for making tools.

William Leonard of Northwestern University proposed that bipedalism evolved in part because it uses much less energy than walking on all fours. [3] Apes and monkeys living in the dense forest can obtain all the food they need within a one-mile radius. In the grasslands, food is harder to come by and may require traveling six to eight miles. The energy expended in acquiring food compared to the energy produced from the food, has important adaptive features for survival and reproduction. The increased efficiency of energy use brought about by bipedalism allows more energy for reproduction.

An additional effect of coming out of the trees was that now our ancestors roamed the savannahs in groups in search of food. Cooperation between individuals and groups of individuals made the task of finding and killing prey easier. These circumstances saw the earliest beginnings of human social structure.

The Human Tree

The ancestors to *Homo sapiens* separated from the chimpanzee about 5 to 6 million years ago *(myr).* [4] What then followed is the evolution of a complex mixture

of different species with varying degrees of human traits. The names and times of appearance and disappearance of these species are shown in Figure 3.

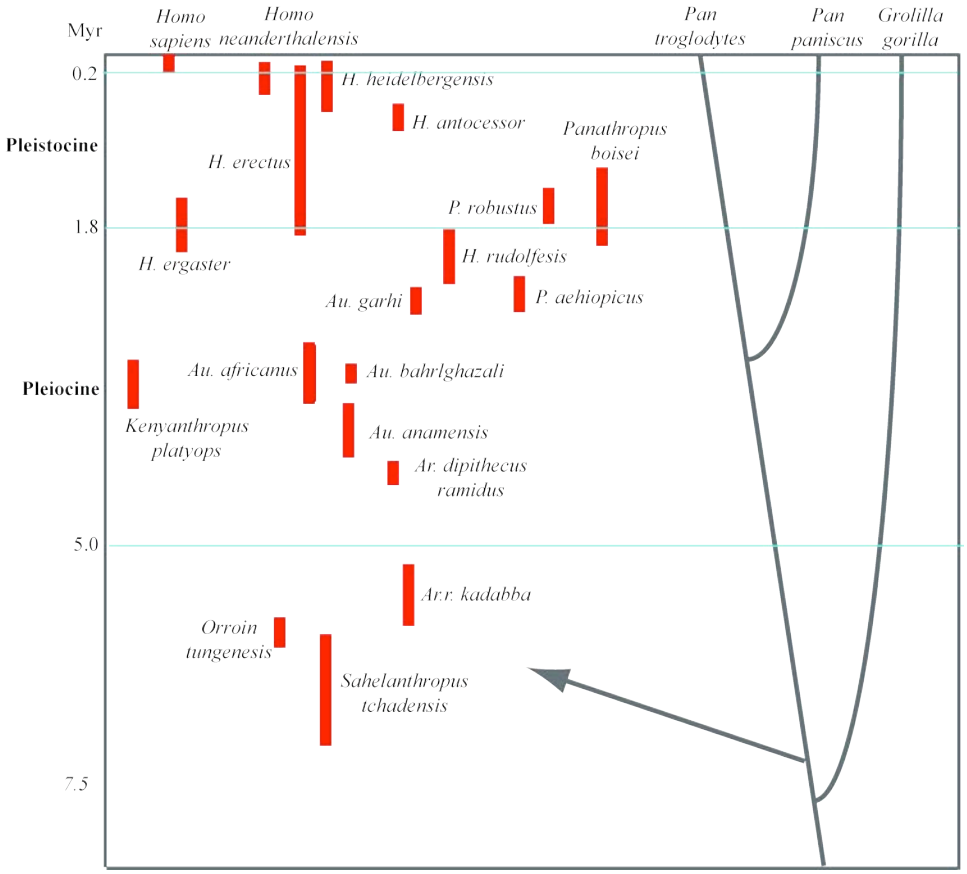


Figure 3. The time scale and evolution of human ancestors (hominids). Pan troglodytes *(chimpanzee),* Pan paniscus *(bonobo),* Gorilla gorilla *(gorilla), and* Pongo pygmasus *(orangutan). After Carroll, S. B. Genetics and the making of* Homo sapiens. *Reprinted by permission. Macmillan Publishers, Ltd.* Nature. *422:849-857, 2003.* [5]

Since the exact ancestral relations between these species are not known they are presented as separate independent bars. Note that *Homo sapiens* had a very late appearance of approximately 200,000 years ago. *Pan troglodytes,* or the chimpanzees, are our closest relatives among living primates. The ancestors in the human line after divergence from the chimpanzee line are referred to as hominids.

African Mitochondrial Eve

I have previously described the analysis of DNA and ribosomal RNA sequences to determine evolutionary relationships between species. The cytoplasmic mitochondria have their own circular DNA, independent of the nuclear DNA. Since the rate of mutation is much greater than for nuclear DNA, it is ideal for

determining evolutionary relationships between species and races that have diverged only recently.

Alan Wilson, Rebecca Cann and coworkers at the University of California, Berkeley, utilized the studies of mitochondrial DNA to examine the relationships between different racial groups. [6] They collected 147 samples from all over the world. In addition to its small size and higher mutation rate, mitochondrial DNA differs from nuclear DNA in that it is passed only from the mother to her offspring. This is because the mother's eggs contain mitochondria which are easily passed to the fertilized egg, while the small number of mitochondria in father's sperm do not pass easily to the egg. This makes analysis of genetic relationships easier.

The phylogenetic tree produced by the analysis of the mitochondrial DNA variation present in these samples indicated that its trunk began 200,000 years ago in Africa. [6] While the woman at the base of this tree was dubbed "mitochondrial Eve" it was only the peculiarities of the technique that made it appear the ancestor was a single person. It was more likely a small group of related individuals. An additional finding of the mitochondrial DNA studies was that there was no crossbreeding between *Homo sapiens* and Neanderthal man.

The human Y chromosome is present only in males and is passed only from fathers to their sons. In addition, there is litle crossing-over in the Y chromosome. Thus, except for random mutations, it tends to be stable over many generations. One of the most interesting uses of Y chromosome DNA studies has been to identify a long line of father to son Jewish rabbis dating back for thousands of years. [7]

Increase in Brain Size in Human Evolution

One of the most remarkable aspects of the evolution of man is the rapid increase in brain size over the past 3 million years. When only a few measures of a few species are included in the analysis, the results suggest there were leaps in brain size followed by plateaus, and then another leap, and that the process was complete after only a few leaps. This is illustrated in Figure 4.

This shows the apparent presence of several distinct brain size groups with rather large gaps in between. This pattern is reminiscent of the punctuated equilibria of Eldridge and Gould and of macroevolution. If true it would require some elaborate theories as to what the environmental factors were that could produce such leaps. However, such theorizing is obviated when a more extensive set of samples is examined.

Henneberg and Miguel [8] examined the cranial capacity and body weight of over 200 fossil homininae (humans, chimps, and gorillas) specimens. These were plotted in logarithmic format against dates in thousands of years before the present (ka BP) (Figure 5).

The regression coefficient for brain size = .95. When analyzed by both date and latitude, they concluded there were no discontinuities through time or geographic latitude. Thus, there were no punctuations and no giant leaps of macroevolution. Evolution of human brain size was occurring in typical Darwinian gradual steps.

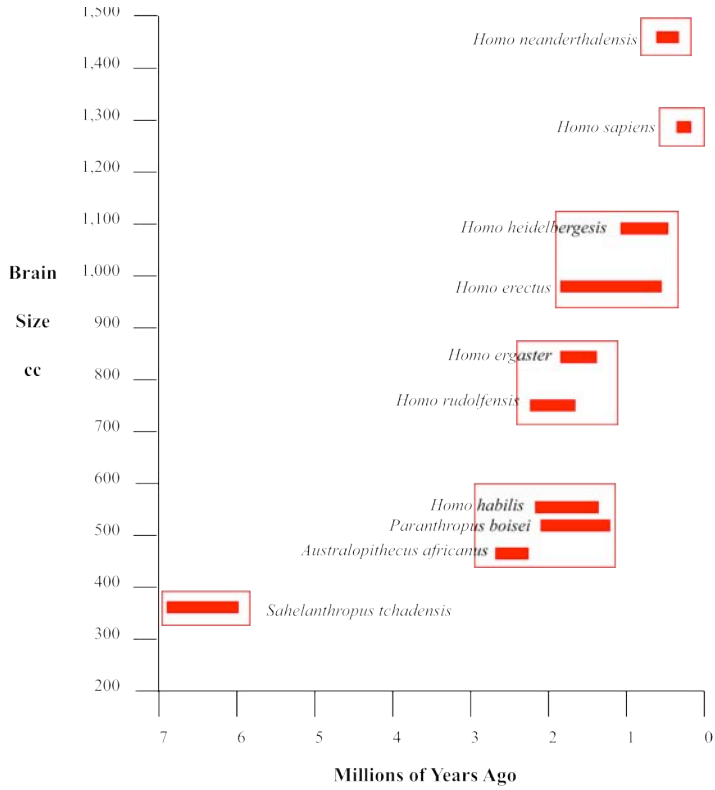


Figure 4. Apparent sudden leaps in brain size. Data from Carroll, S. B. Genetics and the making of Homo sapiens. *Reprinted by permission from Macmillan Publishers, Ltd.* Nature. *422:849-857, 2003.* [7]

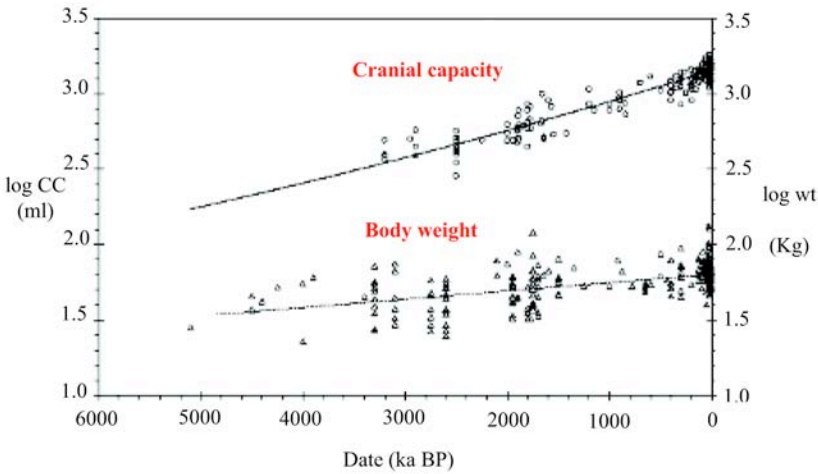


Figure 5. Regression of fossil hominin cranial capacity, log CC (ml) (top), body weight in log kg (bottom), and date in thousands of years before the present (ka BP). From Henneberg and de Miguel. Homo—Journal of Comparative Human Biology. *55:21-37, 2004.* [8] *By permission.*

The evolution of brain complexity. The complexity of the structure of the brain, especially the cortex, has also increased over evolutionary time. This is illustrated by the increase in the number of layers of the cortical plate as shown in Figure 6. Thus, some of the genetic changes between primates and humans produced an increase in the complexity as well as size of the brain.

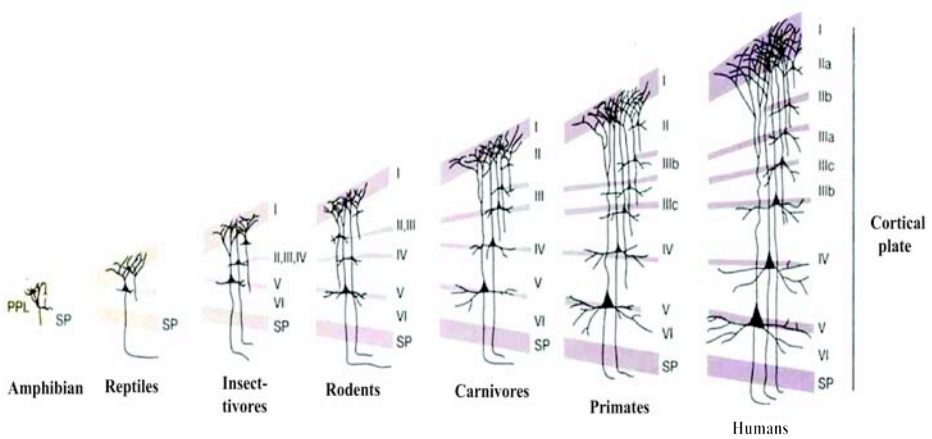


Figure 6. Evolution of the complexity of the cortical plate over time. Starting with layer I, layers are added progressively from deeper first (VI, V) to more superficial (III, II) last. In mammals with ever-larger brains, layers II/III/IV are progressively subdivided into II, III, IV, then IIa, IIb, and so on. From the Comparative Brain Atlas. [8a]

Microscopic changes. Since the 1990s scientists have identified a number of other microscopic features of the nervous system that are unique to humans and to a lesser extent, the higher apes. In 1999 Preuss and colleagues [49] found a layer of the visual cortex that was unique to humans, which may explain why we can detect objects against a background better than other animals. In the same year Hof and coworkers [50] found that a unique type of elongate slender cells called *von Economo neurons,* were unique to humans, the great apes, and whales. These cells may relay nerve impulses faster than other neurons. They are found in areas relating to cognition and advanced planning such as area 10 and the anterior cingulate cortex. [51] An additional microscopic feature, known as minicolumns, consist of 80 to 100 nerve cells bundled together vertically in the cerebral cortex. In Broca's area and area 10 these neurons are wider and more densely packed than in apes and chimps. [52,53]

Role of specific genes. *Microcephalin.* Genetic mutations that cause human disease can often provide clues to the identity of which genes are involved in specific traits such as brain size. A single gene mutation can cause microcephaly (small head) producing severe reduction in brain size without other gross abnormalities. [9-11] Individuals with this condition are mentally retarded and their brain size is comparable with that of early hominids. The gene involved is called *microcephalin (MCH1).* Studies of human populations have shown that *MCH1* contains different polymorphisms, many of which cause amino acid substitutions. The richness of these

polymorphisms is likely to be due to a combination of population expansions and Darwinian selection. The analysis of the ratio of the polymorphisms that caused amino acid substitutions versus those that did not showed positive selection of *MCH1* during the origin of the last common ancestor to humans and the great apes, and corresponds to the drastic brain enlargement from the lesser apes to the great apes. [9,10] Much of the selection occurred on five polymorphisms that were associated with amino acid substitutions. An analysis that was extended back to 30 million years ago suggested that about 45 advantageous amino acid changes occurred over the evolution of our earliest primate ancestors. [11] A subsequent analysis indicated that one variant arose about 37,000 years ago. [10] This might have been relevant to the explosion of symbolic behavior occurring in Europe around that time. [12] These results clearly support the frequent occurrence of beneficial mutations in evolution.

ASPM (abnormal spindle-like microcephaly). ASPM is a second gene associated with microcephaly in humans. Similar analyses of the polymorphisms in *ASPM* also indicate that it experienced strong positive selection in the ape lineage leading to humans. [11,13-16] The evolutionary selection of specific segments of the *ASPM* gene was strongly related to brain size. One variant arose about 5,800 years ago and was quickly swept to high frequency. Direct studies in living humans show no association between *microcephalin* or *ASPM* variants with IQ. [10a]

SIGLEC11 (Saliac acid-binding receptor). This is a gene relevant to surface membranes and present in the microglia, the so-called "glue cells" of the brain. Since it is a human-specific gene [17] it may have played a role in the evolution of *Homo sapiens* and brain size. While other genes are likely to have been involved, these studies show that advantageous mutations in a small number of genes can be associated with a trait as complex as brain size.

Role of nutrition. Nutrition and energy metabolism played a unique role in the evolution of man. The brain in modern humans consumes an inordinate amount of energy, 16 times as much as a comparable weight of muscle. In the resting state the brain uses a whopping 24 percent of an adult human's energy needs [3] compared to 10 percent for nonhuman primates and five percent for other mammals. Leonard plotted the percent of resting energy allocated to the brain for our human ancestors against time in millions of years ago. This plot is shown in Figure 7.

In agreement with the data in Figure 5, this also shows a linear increase over time. A high degree of energy expenditure places a premium on the energy content of food. A meal of 3.5 ounces of animal meat provides up to 200 kilocalories, while a comparable amount of fruit supplies 50 to 100 kilocalories, and foliage supplies only 10 to 20 kilocalories. In addition, cooking food, especially starchy foods, significantly increases the available energy content by making complex carbohydrates more digestible. It has been estimated that the first hominid began using fire 1.8 million years ago. [3]

The spread of grasslands led to an increase in grazing animals. This source of food both provided more concentrated calories and led to hunting and gathering in cooperating foraging social groups. Freeing of the hands allowed the beginnings of the

use of tools to aid in hunting and skinning the prey. The improved dietary quality alone cannot explain why hominid brains grew, but it appears to have played a critical role in allowing that change to take place. [18]

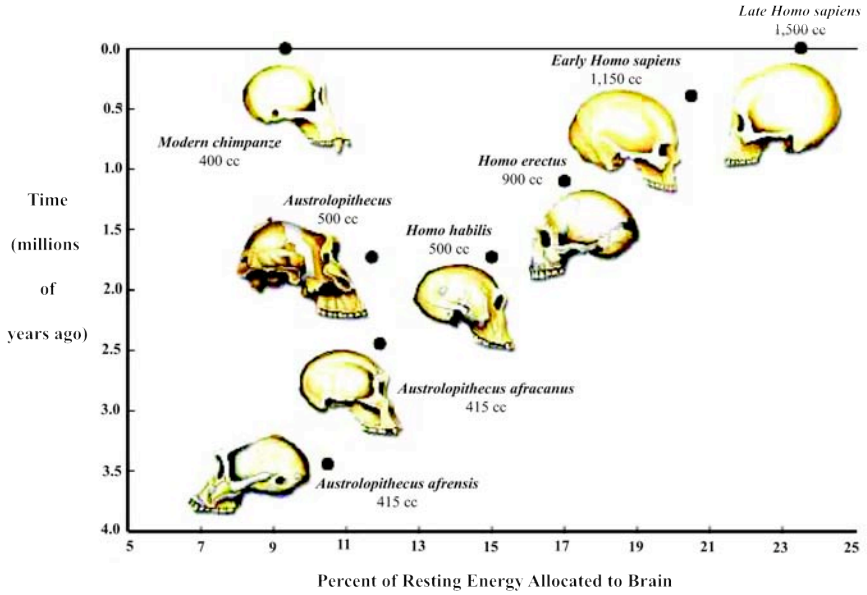


Figure 7. Percent of resting energy allocated to the brain versus time in millions of years ago. From Leonard, W. R. Food for Thought. Scientific American. *2002.*[3] *Drawing by Cornelia Blik.*

Origin of Speech

Larynx. Speech and language is one of the most unique of human traits. It plays a central and critical role in allowing the development of complex, interacting human societies. Phillip Lieberman, a linguist from Brown University, proposed that the critical change that paved the way for the development of speech was the migration of the larynx away from a close association with the jaw to further down in the neck. [19] He suggested that this lower location allowed for the production of a much-varied range of sounds, resulting in the ability to speak. The resulting increased power to communicate paved the way for the development of modern man and civilization.

Brain. As with other aspects of human evolution, new traits did not develop overnight. Even if a relocation of the larynx to the neck allowed speech to develop, the role of the brain in formulating speech also needed to develop. The two parts of the human brain most involved in speech are Broca's area and Wernicke's area. Their location in the human brain and comparable areas in the chimpanzee are shown in Figure 8.

Broca's area is part of the frontal lobe at the left inferior frontal gyrus. Individuals who suffer strokes or other damage to this area have expressive aphasia with impairment in the ability to produce language. Wernicke's area is part of the temporal lobe at the left superior temporal gyrus. Individuals who suffer strokes or other damage

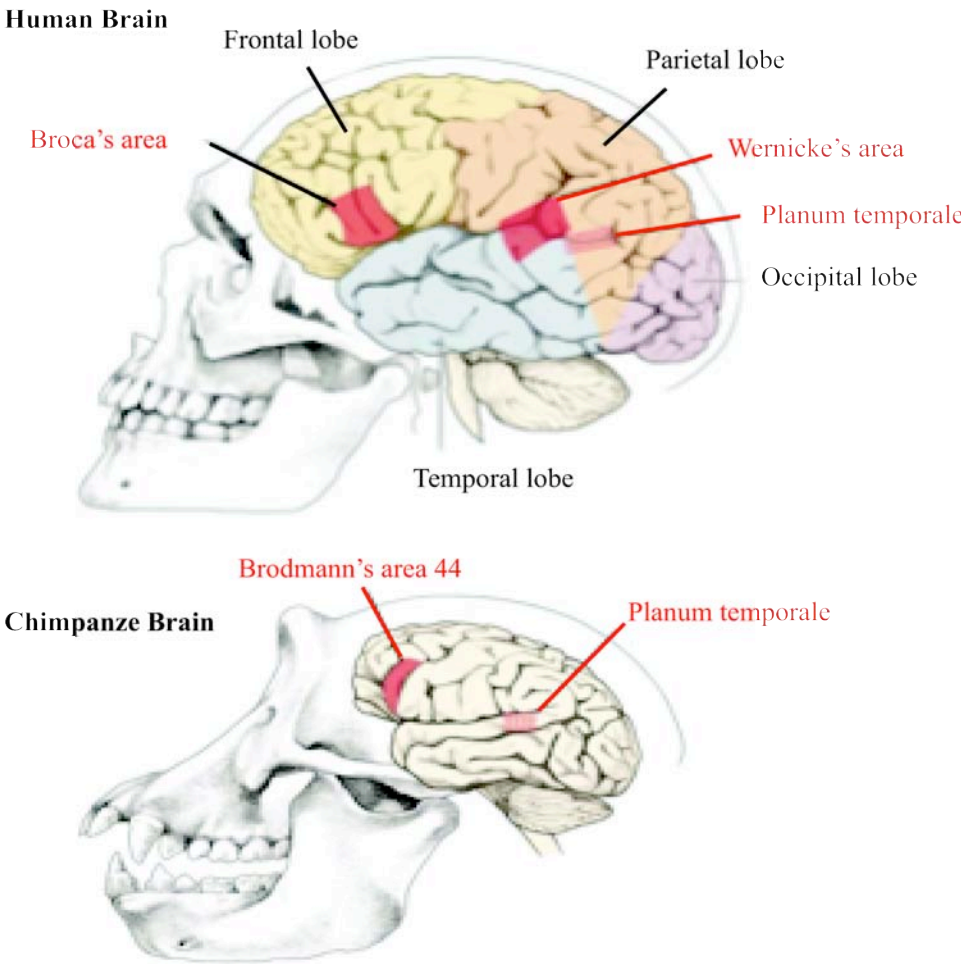


Figure 8. Broca's area, Wernicke's area, and the planum temporale in the human brain and comparable areas in the chimpanzee brain. After Carroll, S. B. Genetics and the making of Homo sapiens. *Reprinted by permission from Macmillan Publishers, Ltd.* Nature. *422:849-857, 2003.* [5]

to this area have receptive aphasia with impairment in the ability to understand language. While speech has a natural sounding rhythm it is jumbled and without recognizable meaning. The planum temporale is a key component of Wernicke's language area. In addition to speech it has been implicated in musical talent. These areas are present on the left side of the brain producing a right–left asymmetry in brain structure. Similar asymmetries have been noted for Brodmann area 44 and the planum temporale in the chimpanzee, suggesting the rudiments of expressive and receptive language in this species and that the lateralization of speech to the left size of the brain occurred prior to the divergence of the human and chimpanzee lines.[20,21] An area homologous to Broca's area has even been found in monkeys where it was involved in facial expressions, especially those involved in communication. It is likely that this area was coopted by human ancestors for control of expressive speech.

The *FOXP2* gene. In humans, severe impairment in expressive and receptive language is occasionally inherited in multiple family members as an autosomal dominant trait. When many individuals in one family are affected, linkage studies can identify the chromosomal region involved. In such a study of a family called KE by Lai et al. [22] the locus was mapped to the short arm of chromosome 7 (7p31) and given the name *SPCH1.* The same authors also found a separate individual with the same speech defect who had a chromosomal rearrangement (translocation) involving the *SPCH1* region. This allowed them to identify the specific gene involved. It was a transcription factor called *FOXP2.* Further studies showed that mutations at the *FOXP2* gene were actually a rare cause of speech and language impairment in children both with [23] and without autism. [24] Sites on several other chromosomes were involved in the most common forms of speech and language defects. [25]

Additional studies continued to support the important role of the *FOXP2* gene in speech. For example, functional MRI studies of individuals carrying the *FOXP2* mutation showed underactivity of Broca's area. [26] In a study in mice, when one of the *FOXP2* genes was experimentally inactivated there was a significant alteration in the ultrasonic vocalizations emitted by the pups when they were removed from their mothers. Finally, an analysis of the mutational changes in the *FOXP2* gene in humans, chimpanzees and mice showed that the human *FOXP2* gene experienced a greater than 60-fold increase in substitution rate compared to the animals without speech. There were two amino acid changes in a transcription domain that were unique to humans. [27,28] This clearly indicated that the *FOXP2* gene played an important role in the evolution of our ability to talk.

General Screen for Genes Involved in the Evolution of Man

It is known that the sequence of human DNA and that of his closest relative, the chimpanzee, is 99 percent identical, [29] attesting to the close relationship between man and this primate cousin. This still leaves room for many differences, and a number of researchers are searching for these differences. The *MCH1, ASPM,* and *FOXP2* genes studied above are what geneticists call *candidate genes.* Based on prior knowledge of their function they are examined because they seem like good candidates, in this case for brain size and speech respectively. However, there are approximately 21,000 human genes, many of which may be involved in human evolution but are not currently clear candidates for the job. To identify these, an alternative to examining specific candidate genes is used to perform mass screens of many genes. *The genetic variations present in different genes can be used to identify those that have been subjected to an unusual degree of natural selection.* The methods for doing this include the following: examining the differences in proteins themselves, the differences in the expression of messenger RNA in individual genes, the differences in DNA sequence, the differences in gene copy number, and the differences in regulatory RNA.

Examination of proteins. This is done by a technique called *two-dimensional gel electrophoresis.* The cellular proteins of a given organ are separated in one direction by size and the second direction by electrical charge. The 2-D gels of cell proteins of the

human and chimpanzee frontal cortex from a study by Enard and colleagues [30] are shown in Figure 9.

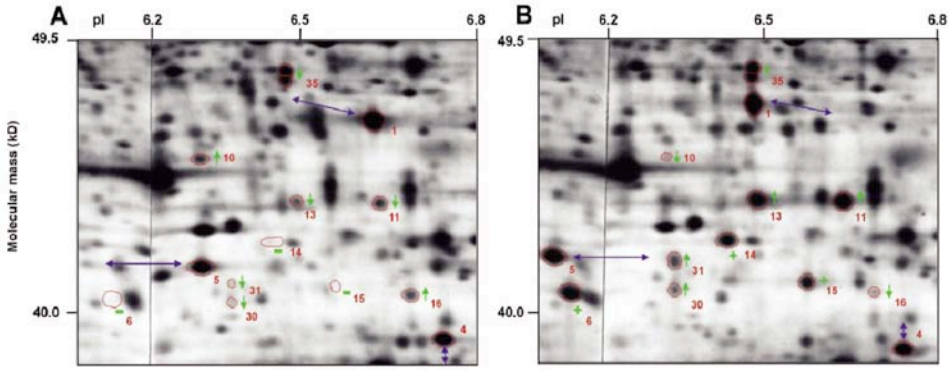


Figure 9. Two-dimensional gel electrophoresis of cell proteins from the frontal cortex (Brodman's area 9) of human (A) and chimpanzee (B). From Enard et al. Science. *296:340-343, 2002.* [30] *By permission.*

The advantage of examining proteins is that differences in mRNA levels do not necessarily translate into differences in protein levels, while examining the actual amount of a protein in the cell clearly does. If a mutation results in the substitution of an amino acid with no electrical charge, like proline, with an amino acid that has a negative charge, like glutamic acid, there will be a net -1 charge difference in the whole protein. These differences in charge due to mutations can be identified by 2-D gels. In the Enard study, brain, liver, and plasma were examined. The brain samples came from Brodmann's area 9, involved in cognition. A total of 538 spots were analyzed for the human-chimpanzee comparison. Of these 7.6 percent showed charge changes while 31.4 percent showed changes in the level of expression. The observed changes were more pronounced in the brain than the other tissues.

Examination of mRNA expression. The advantage of directly examining gene expression by examining the amount of messenger RNA produced is that many more genes can be tested. In addition, the function of most of the genes is known and specific organs or parts of organs can be compared. The technique for doing this involves the use of microarrays, produced by a technology similar to that used in producing tiny (micro) computer chips containing millions of transistors. In this case, instead of transistors, different nucleic acid sequences corresponding to different genes are attached to the microarrays. The basic aspects of this remarkable technique are illustrated in Figure 10. RNA is isolated from the two tissue samples to be examined, A and B. A DNA copy of these sequences is made by reverse transcriptase and in the process one is labeled with a red dye, the other with a green dye.

These sequences are then combined and hybridized to the array to which thousands of nucleic acid sequences corresponding to different genes are attached. The result is examined in a fluorescent microscope. If a given spot contains a sequence present in sample A, but less so in sample B, the spot will be red. If the sequence is present in sample B, but less so in sample A, the spot will be green. If the sequence is

present in approximately equal amounts in A and B, the spot will be yellow. Variations in intensity and color allow the differences to be quantified.

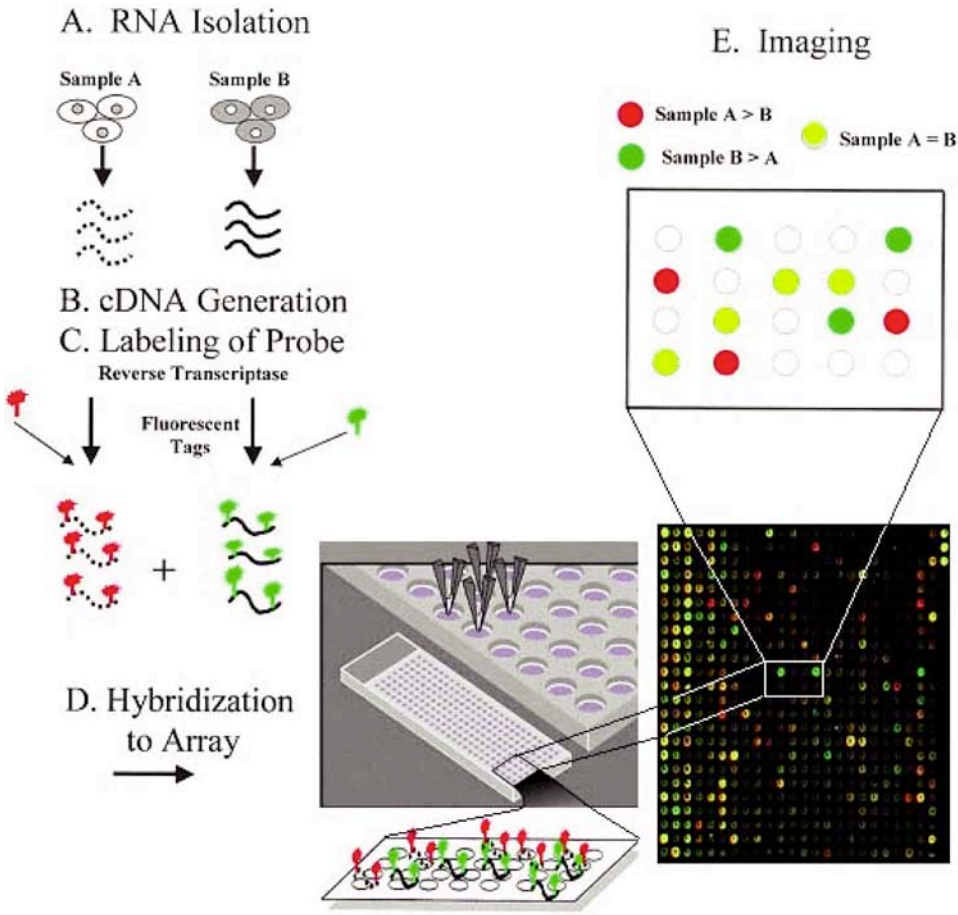


Figure 10. Technique of comparing gene expression using microarrays. [30a] *See text.*

An advantage of this technique is that the expression of genes in a specific organ or organ part can be examined. Thus, we might be interested in the question, "What genes are involved in human cognition and reason?" Examining tissue from those parts of the brain that were involved in cognitive function could assess this. This is what Uddin and colleagues [31] did. They examined human, chimpanzee, gorilla and monkey tissue from the anterior cingulate cortex. Imaging studies show that blood flow is increased in this area when humans are involved in cognitive tasks such as making a decision between two interfering choices—otherwise known as judgment. Approximately 16,000 genes were examined. Based on our inherent sense of superiority it might be anticipated that the evolutionary changes were greatest in the human line. Surprisingly, the greatest changes in gene expression were seen in both the human and chimpanzee lines. This is consistent with the findings that chimpanzees

engage in culture,[32] the use of tools,[33,34] and display rudimentary forms of language,[35] and is a further indication of how closely related these two species are. Up-regulation was noted in genes for energy metabolism and nerve function, consistent with the fact the human brain consumes a large percent of total energy resources.

An alternative method of examining gene expression data is to look at gene expression networks. This refers to how genes are co-expressed in different organs. For example, if gene A is active in the cortex gene B may also be active in humans but not in chimpanzees. Geschwind and coworkers found that in the cortex, 17.4 percent of co-expression networks were specific to humans.[35a]

Examination of DNA sequences. As with the gene expression studies, the advantage of examining DNA sequences is that many more genes can be examined and the precise function of most of these genes is known. However, these studies cannot examine for organ specific differences since the DNA sequence is the same in all organs.

Clark and colleagues[36] compared the sequence of 7,645 genes in humans, chimpanzees, and mice. They chose those genes that had similar sequences in the three animals (orthologs) and whose function was known. At the time this study was done the entire human and mouse sequence was known. This was not the case for the chimpanzee. They compensated for this by amplifying and sequencing the comparable exons from one male chimpanzee. Using a model that allowed the individual domains of the protein sequence to be tested, they identified 873 genes that showed evidence for a significant level of selection. Genes involved in smell showed the strongest selection. Genes involved in amino acid metabolism showed the second greatest level of selection. This is consistent with the prominent role of dietary changes in human evolution. Included in this set would be changes providing increased survival in times of famine. These could be the same genes that predispose to diabetes and obesity when food is plentiful. Other groups of selected genes include those involved in the skeletal development, brain development, embryonic development (homeotic genes) and hearing. This study only examined the coding part of these genes. Other studies are needed to examine the important regulatory sequences of genes.

Nielsen and colleagues[37] examined the sequence of 13,731 genes in humans and chimpanzees. Here the genes related to immune defenses appeared at the top of the natural selection list (Table 1).

Table I. Biological Categories of Genes Showing Positive Selection

From Nielsen et al. *PLOS Biology* 3:976-985, 2005.[37]

Biological Process	**# genes**	**p-value**
Immunity and defense	417	.0000
T-cell-mediated immunity	82	.0000
Chemosensory perception	45	.0000
Biological process unclassified	3,069	.0000
Olfaction (smell)	28	.0004
Gametogenesis	51	.0005
Natural killer-cell-mediated immunity	30	.0018

Spermatogenesis and motility	20	.0037
Inhibition of apoptosis (cell death)	40	.0047
Interferon-mediated immunity	23	.0080
Sensory perception	133	.0160
B-cell and antibody-mediated immunity	57	.0298

Genes involved in defense against viral infections and the important major histocompatibility complex were especially involved. As in the Clark study, there was selection for genes involved in smell and hearing. A large group of genes of unknown biological function was identified. The sequence of many of these suggested they coded for genes regulating transcription factors. They also found that genes involved in spermatogenesis and apoptosis (cell death) were strongly selected for. Table 1 lists all of the gene groups identified as experiencing strong selection.

Surprisingly, Nielsen and colleagues found that instead of showing evidence for strong selection, most brain genes were highly conserved. While this may seem to conflict with the results of Enard and colleagues, they may not. Most of the changes that the Enard study identified were in the level of expression rather than in amino acid substitutions. Nielsen did not test for levels of gene expression or changes in copy number.[37] Later studies,[38,39] including the report of the entire chimpanzee genome DNA sequence,[40] supported the findings of Nielsen and colleagues about the role of transcription and immune factors, but also found that *some of the most rapidly evolving genes were those involved in the function of the central nervous system.*

Changes in promoter regions. Promoter regions are located at the 5' end of the gene and carry the DNA sequences that interact with transcription factors to regulate the degree of expression of the genes. While the DNA sequences between humans and chimpanzees are 99 percent similar, a disproportionate number of these differences may occur in the promoter regions. This would drive the changes in gene expression described above. Some specific examples of this have been reported. For example, the prodynorphin gene *(PDYN)* produces the precursors to brain dynorphin and other morphine-like peptides. Variations at the *PDYN* gene have been reported to be associated with pain perception, social attachment, bonding, learning and memory. Sequencing studies have shown that the promoter region of the *PDYN* gene has accumulated six different nucleotide changes since the divergence of humans from the other primates.[41] This is illustrated in Figure 11.

These changes differ significantly ($p < .0001$) from those expected by chance and indicate that the *PDYN* gene plays an important role is some of the behavioral differences between humans and chimpanzees. They support the concept that many of the important DNA sequence differences between humans and other primates occur in the promoter regions of genes.

Changes in copy number. This refers to gene duplication, one of the major driving forces in evolution. Gene duplication results in an increase in copy number from one to two or higher. Fortna and colleagues[42] examined the copy number of 29,619 genes across five hominid species including humans. Copy number increases

position in 68 bp promoter

Primate	9	15	16	29	62	67
Human	G	G	G	G	C	A
Chimpanzee	A	C	A	A	T	T
Bonobo	A	C	A	A	T	T
Gorilla	A	C	A	A	T	T
Orangutan	A	C	A	A	T	T
Baboon	A	C	A	A	T	T
Pig-tailed macaque	A	C	A	A	T	T
Rhesus monkey	A	C	A	A	T	T

Figure 11. Nucleotide changes in the 68 bp PDYN *gene promoter showing that all of these changes occurred after the divergence of humans from other primates. From Rockman, et al.* PLOS Biology. *3:e387, 2005.* [41]

were most pronounced in humans (134 sites). The genes involved included a number involved in the structure and function of the brain. A study of copy number by Demuth and coworkers showed that human and chimpanzee gene copy numbers differ by 6.4 percent. [42a]

Changes in non-coding RNA. It has been known for years that the expressed genes make up only about two percent of the total genome in mammals including humans. At one time the remainder was referred to as "junk" DNA, suggesting it had no real function. It was then found that the exons or parts of the genes that code for the sequence of amino acids in genes, is interrupted by many introns. These account for 30 percent of the genome. Introns are transcribed into RNA, but for years it was thought that this RNA was simply broken down and destroyed. It is now known that over 60 percent of the genome is transcribed into RNA, and this RNA comes in many different forms and sizes, including microRNA, siRNA (silencing RNA), and ncRNA (non-coding RNA). These originate from the introns, the DNA between the genes, and even the opposite DNA strand from that transcribed to produce mRNA. [43-45] Some of the noncoding RNA sequences are highly conserved while others show rapid changes in DNA sequence from species to species. All of these small RNAs play a major role in gene regulation.

Changes in human accelerated regions. Pollard and colleagues [46] identified 35,000 segments of DNA, averaging 140 bp in length, that showed virtually no change in sequence between mice and chimpanzees. They then searched among these segments and identified 49 that showed many base pair changes when compared to humans. These were termed *human accelerated regions (HARs).* Remarkably, all but one of these *involved genes that coded for non-coding regulatory RNA rather than for proteins.* Of these 49, 24 percent were next to genes involved in brain development, indicating that *many of the HARs were brain-specific regulatory elements that had changed rapidly during human evolution.* The one that showed the most rapid evolution, with 18 base changes since

diverging from the chimpanzee was termed *HAR1.* Further studies showed that this novel RNA gene was expressed in the human cortex between seven and 19 weeks after conception. *HAR1* was expressed in neurons that also repressed reelin, a protein involved in specifying the six-layer structure of the human cortex. Thus, this uniquely human structure of the human cortex, shown earlier in Figure 6, was in part directed by the rapid evolution of a single regulatory gene, *HAR1.*

Another study of the evolution of non-coding DNA was reported by Prabjalar and colleagues.[47] They examined human specific substitutions in 110,549 conserved non-coding sequences and identified 992 with a significant excess of human-specific substitutions. They then examined the genes that were adjacent to these sequences. The most impressive changes were next to genes for *neuronal cell adhesion* proteins that control the interactions between nerve cells. These studies support the concept that changes in regulatory non-coding DNA have played a major role in the evolution of man.

When all studies are combined, they indicate that the DNA sequence of brain genes show many changes in expression and copy number during the evolution of humans. Studies of non-coding DNA identified significant changes in a number of brain-specific genes during the evolution of man.

Among the non-brain genes, the greatest selective forces have occurred in those for smell, hearing, immune defenses (especially against viruses), amino acid metabolism to allow for the greater energy requirements of the enlarging brain, and spermatogenesis.

The fact that human and chimp genes are vastly more similar (99 percent) than they are different (one percent) provides overwhelming evidence that man evolved from the apes.

Sex for all Seasons

While the development of speech led to improved socialization and bonding between humans, a second development also played an important role. Unlike other animals, man is unique in that both males and females are hormonally set up to mate throughout the year instead of only in certain seasons. This sex-on-call feature of humans further contributed to strong kin cohesion and pair bonding. The physiologist Jared Diamond considered this to be a key event in the evolutionary ascendancy of mankind.[48] Spirituality relates to the feeling of being connected with dimensions greater than oneself. Since pair bonding (marriage) and strong kin cohesion (extended family) are important parts of this greater dimension, it is likely that that capability for sex for all seasons played a role in the evolution of man's spirituality.

Other Distinguishing Features of *Homo sapiens*

Unlike finches, where a simple change in beak size can lead to a new species,

the evolution of man was far more complex. It was not simply a matter of the development of a few new features but rather a whole symphony of new features. The following is a partial listing. [21]

Advanced tool-making
Body shape and thorax
Brain structure (Broca's area, Wernicke's area, other areas)
Cranial and facial features
Decrease in protruding jaw
Dimensions of the pelvis
Increased brain size
Long lifespan
Opposing thumb and shortened fingers
Presence of a chin
Prolonged childhood
Reduced hair cover
Relative limb length (shorter)
Skull balanced upright on vertebral column
Small canine teeth
S-shaped spine
Speech and language
Spirituality

Carroll [21] has pointed out that the large number of these changes is consistent with a gradual and progressive accumulation of many advantageous and adaptive polygenic mutational changes. The results of the gene sequence studies of Clark [36] and Nielsen [37] are consistent with the conclusion that man was made by microevolution, not by macroevolution or divine creation.

To some, the idea that humans evolved from the apes is even more disturbing than the idea that all other animal species are the product of evolution by mutation and natural selection. Some of the most dramatic aspects of human evolution include:

- **the descent from the trees to the grasslands**
- **standing upright and thus freeing the hands for multiple tasks, including holding food and babies, killing prey, and making tools**
- **the dramatic increase in brain size and complexity**
- **the development of speech and language**
- **the more rapid evolution of genes involved in smelling, hearing, immune defense, spermatogenesis, and brain**

development
• changes in hormones to allow sex for all seasons
• spirituality
• and many others.

The entire process of human evolution involved multiple steps and thousands of genes. Humans evolved by microevolution rather than macroevolution or divine creation.

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We cannot decide whether the origin of life on Earth was an extremely unlikely event or almost a certainty…

Francis Crick,

Life Itself[1]

Chapter 18

The Origin of Life

One of the most difficult problems in biology to understand is the creation of life on earth. In addition to Francis Crick's comment above, he also said that the origin of life appears at the moment to be "almost a miracle, so many are the conditions which would have had to be satisfied to get it going." [1] Coming from the Nobel Prize-winning scientist who co-discovered the structure of DNA, this comment was seized upon by creationists to validate their position that the origin of life had to be the result of divine creation. The purpose of this chapter is to show that there is clearly a viable alternative.

The Narrow Origin of Life Time Window

One thing has become clear—the time available for the creation of life was fairly short. The earth is 4.6 billion years old, and massive bombardment of the early earth by comets and meteorites apparently occurred until approximately 3.8 billion years ago. Since comets are large and composed predominantly of ice, they are believed to have been the source of the earth's oceans. [2] It was usually felt that the impact of these comets would have produced so much heat that it would have precluded the development of life during the first 500 million years of earth's existence. [3] However, recent observations on zircon microcrystals suggest *the earth may have cooled much more rapidly after its initial formation, perhaps in 100 million years.* [4]

Carbon dioxide (CO_2) in the atmosphere contains two isotopes of carbon, C^{12} in large amounts and C^{13} in small amounts. Since living organisms preferentially use $C^{12}O_2$ a high C^{12}/C^{13} ratio in fossils compared to the ratio in the atmosphere, is a marker for the presence of life forms. The combination of finding microfossils and of analyzing the C^{12}/C^{13} ratio in rocks suggests that life started as early as 3.5 to 3.8 billion years ago. [5,6] Based on initial estimates that it took about 500 million years for the earth to cool this would have left a very narrow time window for the evolution of first life of less than 200 million years and possibly as little as 10 million years. [7] If the earth cooled more rapidly, as the studies of the zircon crystals suggest, the window for the development of life on earth more likely ranged from 10 to 400 million years.

The Miller-Urey Experiment

One of the earliest scientific attempts to understand how life might have gotten

started on earth was the 1953 experiment of Stanley Miller [8] at the University of Chicago. Miller was a graduate student of Harold Urey, a Nobel laureate in chemistry. Urey was interested in the primordial atmosphere of the earth and had just published a theory that it was poor in oxygen and rich in hydrogen. [9] Chemically speaking this would have been termed a *reducing atmosphere* as opposed to the modern oxygen-containing *oxidizing atmosphere*.

Many years prior to this, in 1924, a Soviet biochemist Alexander Oparin published an article entitled "The Origin of Life," [10] and in 1936 wrote a book with the same title. [10] Both were later translated for English-speaking scientists to read. Based on the assumption that the atmosphere of primitive earth contained compounds such as ammonia (NH_3), Oparin proposed that these organic compounds formed a colloidal solution in the primordial ocean. These solutions then coagulated into so-called "coacervates." By absorbing sugars and amino acids, which could serve as catalysts in chemical reactions, a primitive form of metabolism could develop. Competition based on differences in adaptation to the environment brought about a form of evolution to more complex systems. This was in the days before the discovery of DNA and the understanding of its critical role in replication and information storage. As such, this was a "metabolism first" type of model.

In 1929 the British geneticist J. B. S. Haldane [11] wrote an article also entitled "The Origin of Life," and followed this up with a similar article in 1954. [12] Haldane also assumed a reducing atmosphere. Since oxygen (O_2) was absent, ozone (O_3), which protects the earth from ultraviolet rays, was also absent. Prior studies of Baly [13] showed that ultraviolet irradiation of carbon dioxide (CO_2) in water produced complex organic compounds. Based on these facts Haldane proposed that the UV light of the primitive earth resulted in a "hot soup" of organic compounds. As a geneticist, Haldane proposed a replicating "genes first" model in which a small primitive virus-like organism was able to replicate because the necessary precursors were present in this hot soup. This was likely to be an imperfect, error-ridden form of replication, and since replication with errors was the basis of evolution, primitive evolving life was able to get started.

In 1914, Leonard Troland, an American physicist, wrote a remarkably foresighted set of papers in which he proposed that "genetic enzymes" composed of nucleic acids suddenly appeared and were endowed with the ability to catalyze their own replication. [14] These papers were written years before it was recognized that nucleic acids contained the genetic information that was passed from generation to generation.

The reducing atmosphere models of Oparin and Haldane, utilizing methane, ammonia, hydrogen and water to form more complex precursors of life, were combined and called the *Oparin-Haldane hypothesis.* This hypothesis is illustrated in Figure 1.

In 1953, drawing from this hypothesis, Stanley Miller sought to determine experimentally if organic compounds really could be formed in these primitive earth conditions. Chemistry Nobel laureate Harold Urey, Miller's advisor at the University of Chicago, was so skeptical that he did not encourage his student to use this as a Ph.D. dissertation. Miller persisted and enclosed water vapor (H_20), ammonia

(NH_3), methane (CH_4) and hydrogen (H_2) in a glass flask and used electrical discharges, simulating lightning, as a source of energy to facilitate chemical interactions.

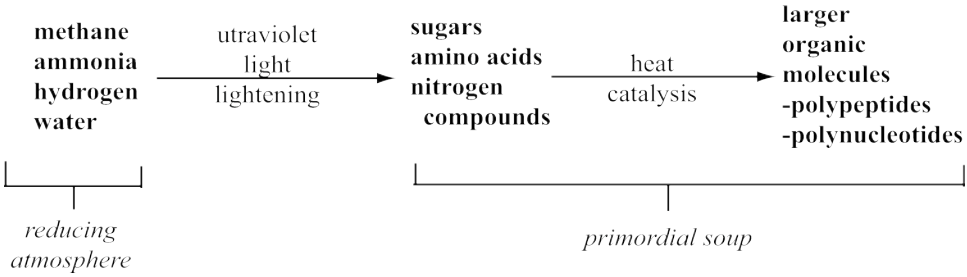


Figure 1. The Oparin-Haldane Hypothesis

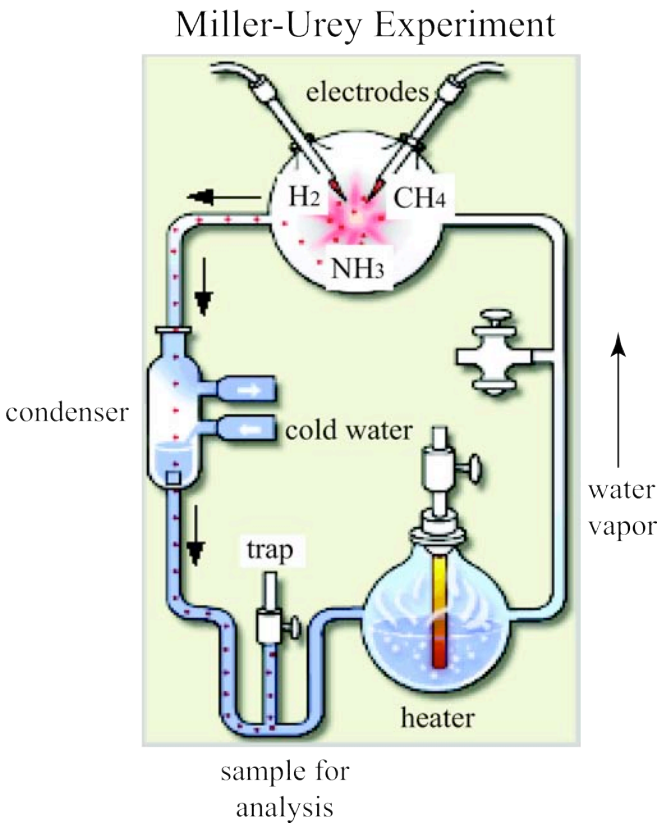


Figure 2. The Miller-Urey Experiment (see text). [14a]

Even Miller was astonished by the results. At the end of a week of allowing these reactions to occur, the water in the flask was deep red and turbid. About 10 percent of the available carbon was converted into organic compounds of which about two percent were amino acids, the building blocks of proteins. [8] These remarkable findings stimulated research around the world and started a new field of investigation in primitive earth or prebiotic chemistry. Importantly, some of these studies also showed the formation of short chains of amino acids known as *peptides.* [15p82]

In 1969 a meteorite fell in Murchison, Australia. Analysis of its chemical composition showed that it contained the same amino acids in the same relative amounts as the compounds produced in Miller's experiment. [16] These findings supported the Oparin-Haldane hypothesis about how organic precursors to primitive life could have been made. The Miller-Urey experiment was only a start toward understanding the possible origins of life on earth.

Creationists' Objections to the Miller-Urey Experiment

The conclusion that the earth's early atmosphere had a lot of hydrogen and was thus reducing, was based on studies of the atmosphere of the larger planets and the widespread presence of hydrogen in the universe. Although the smaller planets like the earth did not have the gravitational force to retain hydrogen in the atmosphere, the secondary atmosphere was still considered to be reducing.

Later evidence suggested that the primitive atmosphere of the earth was derived from volcanic action. Since modern volcanoes did not emit hydrogen, [17] the reducing nature of the early atmosphere was called into question. It was suggested that since water in the atmosphere could be broken down by UV light into oxygen, which would be retained in the atmosphere, and hydrogen would be lost because of its light weight, some oxygen was likely to be present.

A non-oxidizing or reducing atmosphere was necessary to preserve and protect the early organic compounds. The Oparin-Haldane scenario would be significantly weakened by the absence of a reducing atmosphere. The creationists, always searching for any conflicting opinions among scientists, have leapt on these developments to discredit the Miller-Urey experiment [18] and by implication, any non-divine origin of life. However, as often occurs in science, advances in knowledge bring improved clarity to complex issues. This improved clarity showed that there were only trace amounts of oxygen in the early atmosphere; there was a hydrogen-rich early earth atmosphere; comets and meteorites delivered huge amounts of organic compounds to the earth; and underwater hydrothermal vents provided the reducing conditions suitable for the origin of life.

There Was Virtually No Oxygen in the Early Earth's Atmosphere

The level of hydrogen and methane in the atmosphere of primitive earth is still debated. Some have suggested that methane was present and that the atmosphere really was predominantly reducing. [15p114] There is no debate about the fact that there was only a trivial amount of oxygen in the atmosphere prior to 2.1 billion years ago. [19,20] This was clearly not enough oxygen to produce an oxidizing atmosphere. The real issue has been, "Why did it take 1.5 billion years after life began before significant levels of oxygen accumulated in the atmosphere?" The critical point is that even when new Miller-type experiments were performed using various corrected atmospheric conditions the same wide range of organic compounds was produced. [21,22]

There Was a Hydrogen-Rich Early Earth Atmosphere

The escape of hydrogen from the early earth's atmosphere is likely to have occurred at a rate that is one hundred times slower than previously thought. [23] This suggests that the production of prebiotic organic compounds in such an atmosphere would have been more efficient than either of the following two mechanisms—delivery from space or hydrothermal vents.

Comets and Meteorites Provide Prebiotic Organic Compounds

One of the more incredible facets of our solar system is that comets, meteorites and interplanetary dust are loaded with a wide range of organic compounds, including amino acids, hydrogen cyanide, formaldehyde, adenine, and many others.[24] The amount of organic material currently deposited on the earth by meteorites and interplanetary dust is estimated to be about three hundred thousand kilograms, or 300 metric tones per year. During the early period of heavy bombardment this rate may have reached 50,000 tons per year. This rate would have produced the current total biomass in approximately ten million years.[15,25]

Comets are the richest source of organic compounds.[26p186,27] This organic material makes its way to earth in the form of micrometeorites, which are formed when the comets pass close to the sun. These micrometeorites are 50 to 500 um in size and currently reach the earth in huge amounts of 20,000 tons per year.[28] They contain tiny grains that contain clays, oxides, and sulfides of metals, which can act as catalysts in chemical reactions. As such they would function as chemical factories for the production of organic compounds.

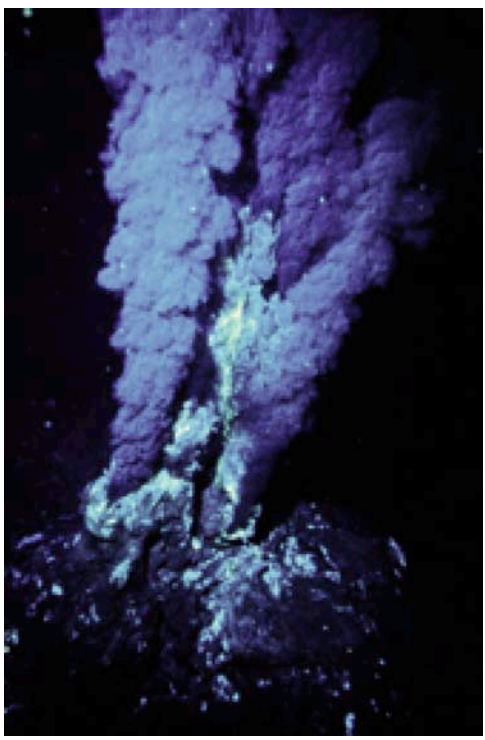


Figure 3. Undersea hot, volcanic, hydrothermal vents.[32a]

In addition to providing a rich source of organic compounds in prebiotic earth, it has also been proposed that cosmic debris bearing iron and carbon could contribute to a reducing atmosphere and lead to the production of hydrogen, methane, and ammonia in prebiotic earth, producing the conditions assumed in the Miller-Urey experiments.[26,29,30]

Hydrothermal Systems

The bottom of the ocean contains many volcanic, hydrothermal vents (Figure 3). These provide a remarkable ecologic niche. The gas from the vents contains carbon dioxide and methane[31] and can serve as a hot reducing environment for the synthesis of prebiotic organic compounds.[32]

These vents have been proposed as sites for the evolution of life itself.[32,33] The high temperatures characteristic of these volcanic vents are especially suitable for the evolution of the heat-loving, or thermophilic, Archaea.

The complaints of Wells[18] and other creationists about the Miller-Urey experiments are without merit. All evidence indicates that

there was virtually no oxygen in the earth's atmosphere for 1.5 billion years after life, that it contained significant amounts of hydrogen and thus the primitive atmosphere really was predominantly a reducing environment. In addition, a huge amount of organic material was deposited on early earth by comets, cosmic dust, meteorites and micro-meteorites. Finally, Archaea, one of the very earliest forms of life, probably originated in the hot and reducing environment of undersea hydrothermal vents.

Theories of the Origin of Life

The Miller-Urey experiments related to the experimental examination of the Oparin-Haldane hypothesis for the synthesis of prebiotic organic compounds. This is a long way from the evolution of life itself. There have been many proposals for how such evolution may have occurred. The variables for the different models include the type of atmosphere (reducing or neutral); which system came first? (metabolism, cell membranes, protein synthesis, or nucleic acid-based replication); what was the source of energy? (feeding on organic food [heterotrophs] or light rays and chemicals [autotrophs]); which chemical world was involved (an RNA world versus a protein world); and which real world was involved (the earth versus an extraterrestrial origin of life).

It is not my purpose here to review the extensive literature on the origin of life in a short chapter. The excellent books of Iris Fry's *The Emergence of Life on Earth,* [15] and Christian de Duve's *Life Evolving* [34] and *Cosmic Dust,* [35] do this. It is my purpose to show that the creationist's complaint that the rapid evolution of life on primitive earth was so difficult that only a divine creator could do it, is false.

In the following paragraphs I have chosen one of the models that I find to be the most reasonable. This is the protometabolism-transfer RNA model of Nobel laureates Christian De Duve [34] and Manfred Eigen. [36-38] This model is summarized in Figure 4.

Protometabolism—A Chemical World

The first aspect of this model is *protometabolism.* One of the primary problems in modeling the chemistry of the origin of life relates to the issue of "Which came first, the chicken or the egg?" In the origin of life this translates to, "Which came first, proteins or nucleic acids?" It is clear that there are two critical parts of both current and primitive life. These are A) nucleic acids which code for the genes that produce the proteins and enzymes (replicases) that allow the nucleic acid to be made and replicated, and B) protein enzymes that carry out this synthesis and replication. Without the protein the nucleic acid cannot be synthesized and replicate. Without nucleic acids the protein enzymes cannot be made. This was a classic catch-22, a classic chicken or egg. *There is only one clear answer—they evolved together.*

It was also clear that the first nucleic acids had to be RNA, not DNA. RNA is single-stranded and much easier to make and replicate than DNA. Because it is single-stranded it can form complex secondary structures by virtue of some of the

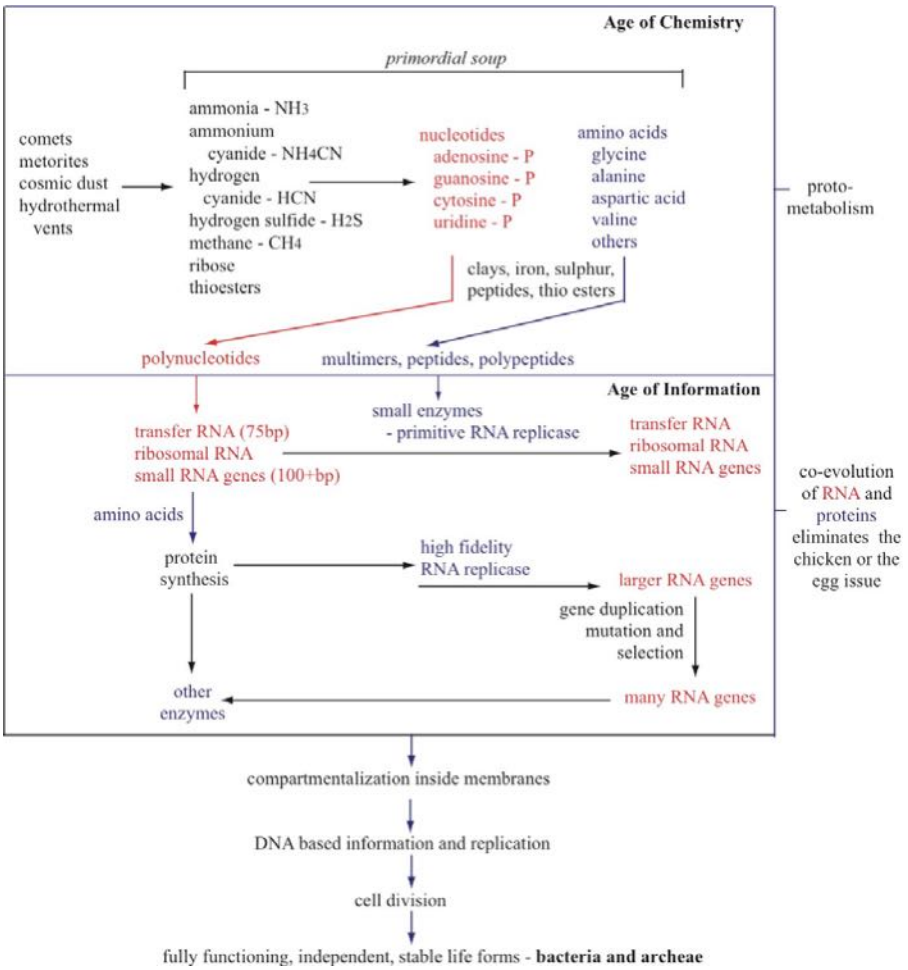


Figure 4. A protometabolism-transfer RNA model of the origin of life. The RNA parts are in red, the peptide and protein parts in blue. See text.

bases pairing with themselves (see transfer RNA in Figure 6 as an example).

It has actually been shown that these complex RNA structures can, in some circumstances, function as enzymes.[39] These are called *ribozymes.* It has been proposed that this would solve the "Which came first, RNA or enzymes?" problem, since RNA could be both a nucleic acid and an enzyme. This model was called *an RNA world.*[40] As elegant and exciting as this would be, De Duve[35] properly points out that this still did not answer the question of how such a complex piece of RNA got there in the first place. He felt that many more preparative steps had to be in place before this could happen. He termed these steps *protometabolism,* referring to chemical steps preceding the formation of complex structures such as RNA. This could be called a chemical world. The following are some aspects of this chemical world.

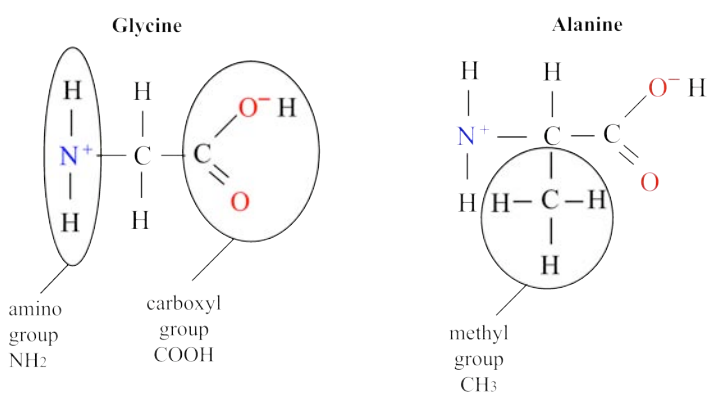
The primordial soup. The primordial soup that figures prominently in this protometabolism model does not refer to the oceans as a whole. That would represent a soup that was too dilute to feed anyone and certainly not feed the origin of life. The primordial soup concept refers to tidal flats or isolated lagoons where the evaporation of water can result in very concentrated solutions of prebiotic organic compounds.

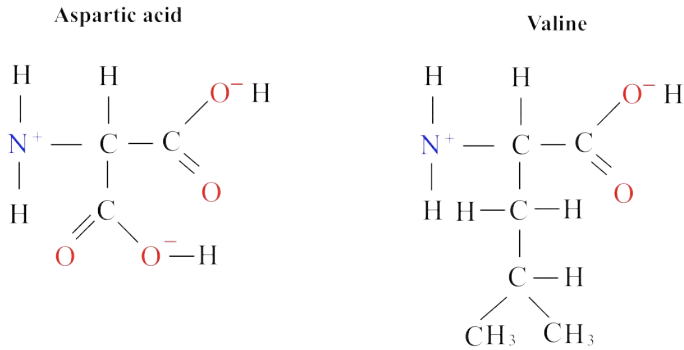
Synthesis of adenine. One of the most critically important organic molecules involved in prebiotic soup was adenine. When combined with ribose sugar it formed adenosine, part of the energy-storage compound adenosine triphosphate or ATP. In 1961 Juan Oró [41] found that adenine could be formed in a single step from ammonium cyanide, a component of the prebiotic soup.

Non-enzyme catalysts by minerals. Catalysts are critical for any form of metabolism. They accelerate chemical reactions many thousand-fold by holding the chemical reactants close to each other. Enzymes are the catalysts of living organisms. The problem is they are composed of long stretches of different amino acids called proteins, and did not yet exist in prebiotic conditions. However, many organic compounds, especially those with negatively charged phosphorus or carboxyl groups (COO-), are attracted to positively charged inorganic compounds, especially those containing metals such as magnesium (Mg++), copper (Cu++), calcium (Ca++), iron (Fe++), zinc (Zn++), cobalt (Co++) molybdenum (Mo++) and manganese (Mn++). It is clearly no accident that many of the enzymes of modern life have these metals as part of their structure. De Duve called these similarities between prebiotic life and modern life *concordance.*

Some of the most frequently studied inorganic compounds that were considered as important as prebiotic catalysts were hydroxylapatite, [42,43] clay, [43] and iron-sulfur compounds (iron pyrite or fool's gold). [44,45]

Polymerization of amino acids. Polymerization (poly = multiple, mer = part) refers to the joining together of individual parts into a larger whole. It is similar to the phrase carried on the eagle of the U. S. Great Seal, *e pluribus unum,* meaning "out of many, one." One could say the original 13 colonies were polymerized into one nation. The non-enzymatic polymerization of prebiotic amino acids could provide for the formation of primitive enzymes. How could this take place? Four of the most





common amino acids in the Miller-Urey type of experiments, in comets and meteorites, and in the prebiotic earth, were glycine, alanine, aspartic acid, and valine. The structure of these amino acids is as follows:

In order to polymerize amino acids it is necessary to form a peptide bond between the amino group of one amino acid with the carboxyl group of a second amino acid. This reaction is accomplished by removing an -OH group from the CO-OH carboxyl group and a hydrogen from the NH_2 amino group to form water and a peptide bond. This is shown in Figure 5.

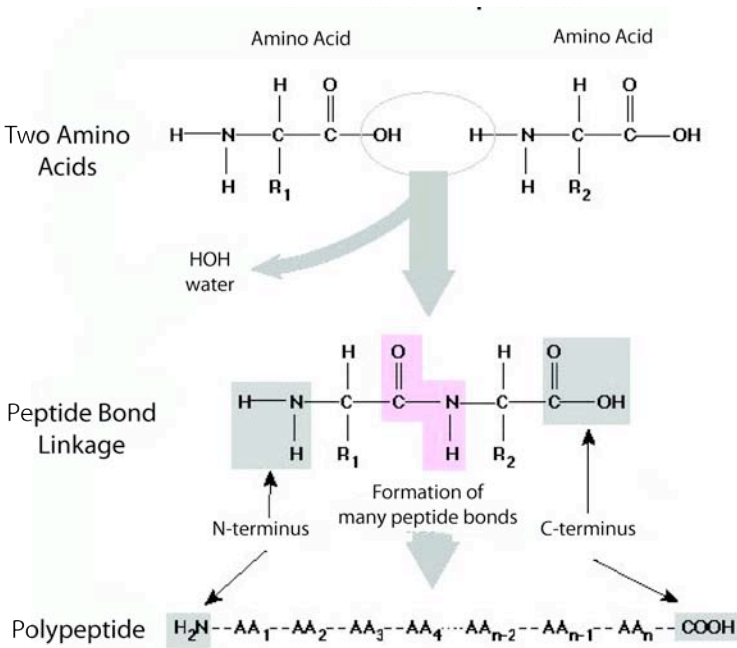
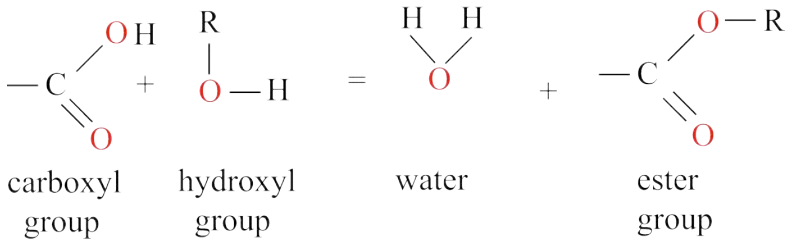


Figure 5. Diagram of the formation of a peptide bond during the polymerization of amino acids to form polypeptides. [45a]

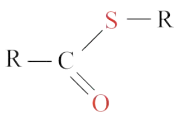
In modern life this is accomplished by ribosomal RNA acting as a ribozyme. How could this important reaction have occurred in prebiotic times? One answer was provided in 1958 by Sidney Fox. [46] He found that simply heating a mixture of amino

acids for three hours at 170°C produced a protein-like complex he called proteinoids that had some weak enzyme activities. A more satisfying possibility involves *thioesters.*

Thioesters. Esters are formed when an hydroxyl group (-OH) interacts with a carboxyl group (-COOH) with the removal of water as follows:



Thioesters are esters with a sulfur molecule attached where the oxygen was.



The R refers to any chemical group. The thio group was derived from hydrogen sulfide (H_2S) that pervaded the prebiotic world and produced a putrid rotten egg smell. Theodor Wieland [47] found that when amino acid thioesters were mixed together in water, the amino acids polymerized to form peptides *even in the absence of any catalyst.* This ability to form primitive amino acid polymers that could serve as primitive enzymes provided an important step in the chemical world of protometabolism.

A thioester world. [35p43] As noted previously, adenosine triphosphate or ATP is an important energy source in modern organisms. De Duve felt that ATP was too complex a molecule to have been present in the protometabolism step. However, thioesters also contained high-energy bonds and were energetically equivalent to ATP. They could substitute for ATP and produce high energy inorganic P~P pyrophosphate bonds as a source of energy for polymerization of amino acids and the formation of nucleosides in the prebiotic soup. Thioesters provided the prebiotic world with two essential ingredients, energy and catalysis. [35p44] These above steps are summarized in Figure 4 in the top box called *protometabolism.*

The Co-Evolution of RNA and Proteins

The bottom box in Figure 4 is labeled "The co-evolution of RNA and proteins eliminates the chicken or egg issue." This stage represents the transition from the age of chemistry to the age of information. The following are a number of basic facts and issues involved in this aspect of the model.

Origin of the Four-Letter Code. As described previously, the secret of DNA replication and transcription is the pairing of guanine with cytosine by three hydrogen bonds and adenine with thymine (uracil in RNA) by two hydrogen bonds. Because the G-C pairing involves three hydrogen bonds, it is more stable than the U-T or A-T paring. Since it is likely that there were many other bases in the

primordial soup, how were these specific ones chosen? The G-C and A-T based are typical of DNA, but DNA did not even exist yet. As shown in Figure 6, even though RNA is single-stranded it takes on a complex secondary structure by just this type of base pairing. Not only does this secondary structure provide RNA with much of its functional capacities, such as serving as ribozymes, it also protects itself from being destroyed. Single-stranded RNA is much more labile than double stranded RNA. Selecting the G, C, A and U bases would provide a very evolutionary force for ensuring that polymers would survive better than those that could not have a lot of secondary structure.

Transfer RNA. Transfer RNAs were likely to play a critical role in early evolving life. [36,37] This is because they are short (about 75 base pairs) and they provide a critical aspect of the genetic machinery. As shown in Figure 6 transfer RNAs serve as a bridge between the sequence of the bases in primitive genes and the amino acids assembled to form proteins. Just as the secondary structure of RNA was likely to have played an important role in selecting G, C, A and U bases, the attachment of amino acids to transfer RNA may have contributed to their stability and improved their ability to replicate. [35p62]

Transfer RNAs would play a critical role in evolving the early genetic code. Since GC-rich RNAs were more effective at base pairing than AT-rich RNAs, and since the middle position of the three-letter code can be any nucleic acid, the four initial codes were likely to be GGC, GCC, GAC, and GUC, coding respectively for glycine, alanine, aspartic acid, and valine. Sequencing studies indicate that these are, in fact, the most common amino acids in primitive proteins. [38] A genetic code based on the use of three nucleic acids would provide coding for 64 amino acids. However, because of redundancy in the code [p24] there are only 20 amino acids. Recent studies [48] suggest that the use of a two base code preceded the three base code. This would have considerably simplified the evolution of the genetic code. In addition, the temperature-sensitive amino acids glutamine and asparagine would have been left out. This would be consistent with a hot rather than a cold primordial soup.

Small is beautiful. In addition to the transfer RNAs, everything else also had to be small and short. Since the replication enzymes were primitive and not too accurate, the primitive genes had to be short, otherwise, the number of errors would be too great. Since the earliest protein enzymes were probably random chance combinations of amino acids and peptides, they would be short and their enzymatic functions would be crude and primitive. The fact that primitive enzymes were short negates one of the common arguments of creationists that the probability of the random formation of modern proteins that are hundreds of amino acids in length is so remote as to constitute a *Basic Argument for Improbability.* By contrast, there is a very high probability of forming short primitive enzymes in which a wide range of sequences could all work. Short primitive enzymes evolve into longer, more precise enzymes by mutation and natural selection.

Ribosomal RNA. Ribosomal RNA would also be one of the early primitive RNAs. In the absence of protein it can act as a ribozyme and catalyze the formation of peptide bonds. [49] This, in addition to the genetic RNA, was probably an important

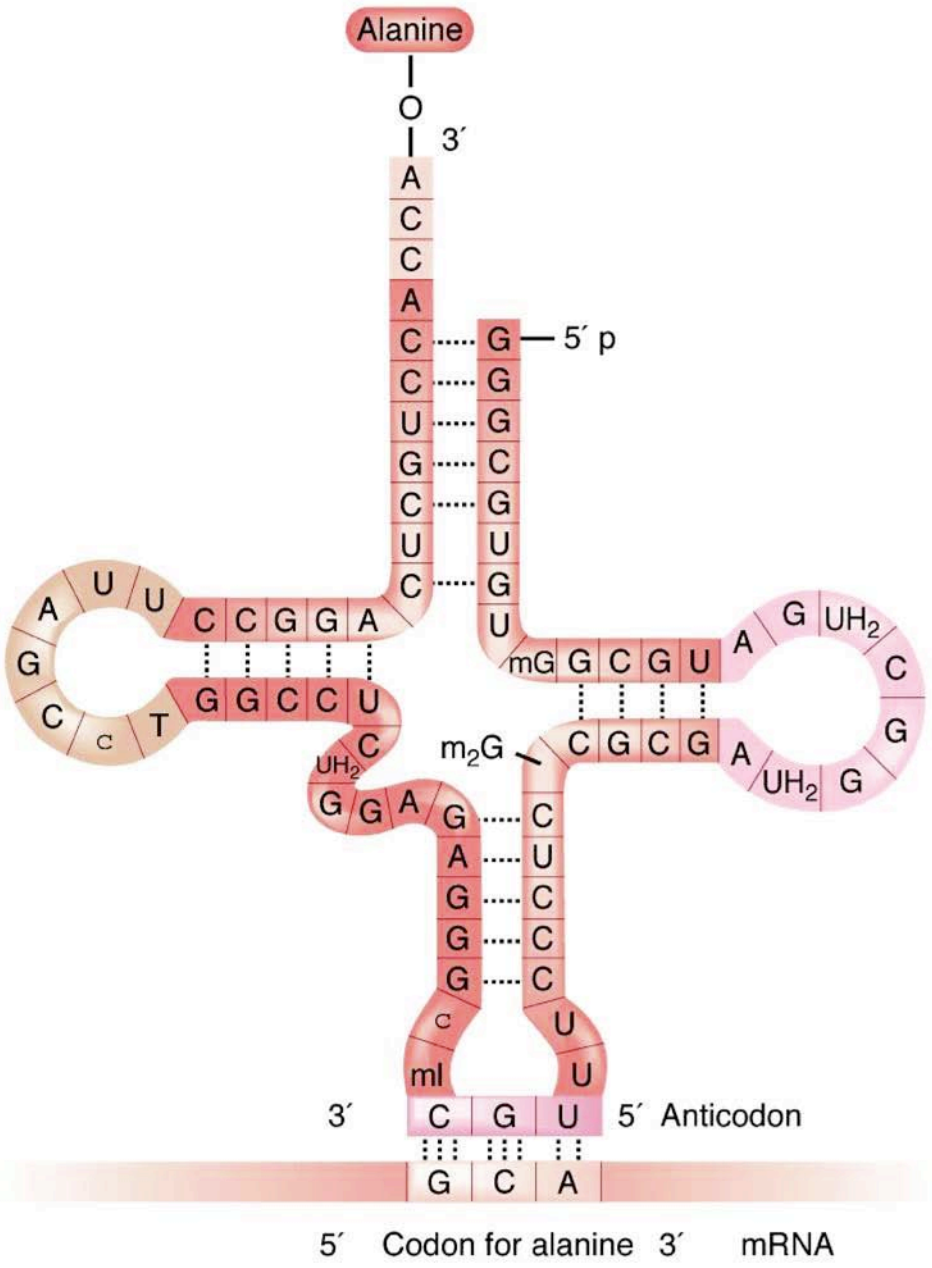


Figure 6. Alanine transfer RNA. The codon GCA in RNA is recognized by base pairing with the anticodon CGU, which in turn is attached to a short transfer RNA with a cloverleaf secondary structure and attached to the amino acid alanine. Thus, GCA (or GCC, GCU, GCG) coded for alanine in the resulting protein. [37a]

early biotic nucleic acid.

The linkage of energy and information. The utilization of ATP, CTP, GTP, and UTP as precursors in the synthesis of RNA is unusually efficient for primitive organisms since these are the same tri-phosphates that serve as important sources of energy in cell metabolism. The di-phosphates ADT, CDP, GDP, UDP and pyrophosphate P~P, are also energy sources. Thus, biological energy and information are intimately linked in nature. [34] These energy sources were likely to have played an important role in chemical reactions preparatory to the appearance of the first RNAs.

Co-evolution of RNA and protein. Since this is a truly irreducible system, all components would have to have evolved together. This was possible since many different short RNA and protein sequences were present in the primitive soup, and those components that worked were the ones utilized. These functioning mixtures of RNAs were called *quasispecies* by Eigen [38] and the complex dynamic interactions of multiple RNAs and protein was termed a *hypercycle.* This co-evolution eliminated the chicken or egg and the catch-22 problems.

Compartmentalization by membranes. Initially much of the assembly of primitive RNA and peptides took place in the primordial soup and was not sequestered behind cell membranes. This had the advantage that the solutions developed by multiple independent copies of primitive proteins or nuclei acids sequences could be shared. For example, the different transfer RNAs could be shared and the ones that worked the best would be used. The first genes would be short and the proteins they produced would be short. The minimum number of genes and enzymes required for independent cellular life is about 300. [50]

Evolution of a DNA-based genome. A double-stranded DNA genome is more stable than an RNA genome. The development of a DNA-based genome was most likely initiated by the development of a reverse transcriptase enzyme. This is well known in modern organisms and produces DNA from an RNA template.

Summary. All of these elements are present in the model shown in Figure 4. Since no one was there, it will be very difficult to prove the exact mechanism of the origin of life. However, the heavens, the earth, and present life forms have all left us with a wealth of clues. The above model cannot claim to be a proven mechanism for life's origins, but it is a reasonable model that is consistent with a wealth of clues. This model shows that the origin of life was not so intractable that only a divine creator could do it.

The question of "How did life first evolve on earth?" is one of the most intriguing questions in biology. The time window for this to occur may have been as narrow as ten million years. Examination of the wide range of modern organisms has provided a wealth of clues about some of the necessary chemicals and conditions required. While many models have been proposed, some are clearly better than others. One of the most likely is a protometabolism-transfer RNA model, consisting first of *The Age of Chemicals* providing the necessary organic compounds, followed by *The Age of Information* involving

the co-evolution of polymers of RNA and protein. This model shows that the origin of life was not so intractable that only a divine creator could do it.

Are We Alone?

One of the most impressive lessons learned is how rapidly life evolved, in as little as 10 million years, once the conditions on earth were suitable. This returns us to Crick's statement at the beginning of this chapter of "whether the origin of life on Earth was an extremely unlikely event or almost a certainty." The answer appears to be, it was almost a certainty. Given that there are trillions of planets in the universe that could support life it is virtually inevitable that life exists on many of these, forming what De Duve referred to as the universe's "vital dust." [35p292] Does this diminish us? Of course not. Will we ever communicate with these other forms of intelligent life? Given that most are over 100,000 light years away, probably not. However, one thing is certain, if God exists and is the personal God to all intelligent beings, he is not only going to be very busy but he also has a very difficult task. The speed of communication would have to vastly exceed the speed of light, yet nothing is supposed to exceed the speed of light. These required attributes severely stretch the credulity of our rational brain.

Given the rapidity and apparent ease of the origin of life on earth, it is likely that many of the other planets in the universe also have intelligent life. If God exists and is the personal God to this huge number of beings he has a very difficult task. The speed of communication would have to vastly exceed the speed of light. Since nothing is supposed to exceed the speed of light these required attributes severely stretch the credulity of our rational brain.

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Chapter 19

Evolution: Conclusions

The concept that a supreme being created us is an integral part of many religions. When we are born it was by the choice of "Our Creator." During our lifetime we are spiritually guided by "Our Creator," and when we die we go to meet "Our Creator." From the earliest times that humans acquired the ability to have such thoughts and when scientific alternatives were not available, the spiritual world and a belief in a supernatural force was evoked to explain our most critical questions such as, "Where did we come from?", "What is our purpose in life?" and "Who created life?" Other questions relating to our place in the world included "Did God put us at the center of the universe?" If this was true, then the sun must revolve around the earth.

When Galileo began to use the observational powers of science and actually peered into a telescope to view the solar system, he concluded that the earth revolved around the sun. The Catholic Church, which at the time represented the major Western form of organized religion, initially fought Galileo's conclusions. This concept, however, was not a major theological issue, and as the scientific evidence became overwhelming for a heliocentric solar system, religious resistance to the concept faded, culminating in a 1984 apology by Pope John Paul II for the manner in which Galileo was persecuted. [1]

However, when Darwin published *The Origin of Species,* many theologians found the concept that perhaps God was not "the Creator," and perhaps the world did not form in only seven days, and perhaps man was not created in the image of God but in the image of the lowly chimpanzee—way too much to accommodate. In the Middle Ages and even in modern times, many believed in the literal truth of the Bible. If God spoke every word, then every word had to be literally true. Under this view, the theory of evolution was the ultimate enemy. This view, however, was not universal. Many theologians assumed that men wrote the Bible and these men were simply trying to put into writing what they thought was the word of God. Since men are fallible, the Bible could be a metaphor for the truth rather than the absolute literal truth. Darwinism did not threaten theologians who held to this view, and many did hold it. [2]

There was, however, a very vocal minority who continued to believe in the literal truth of the Bible. These were the creationists. More precisely, they were the Young Earth Creationists. This movement was much stronger in the United States than in

Europe. In its effort to provide for freedom of religion for all citizens, the United States Constitution opted for the separation of church and state. A major challenge to this came in Tennessee in 1925 with the famous Scopes "monkey trial." Here, in the heart of the Bible belt, creationists attempted to prevent the teaching of the theory of evolution in the schools. This led to a classic battle of legal titans, Clarence Darrow versus William Jennings Bryan. Even though Darrow lost the case, the scientific position of the Young Earth Creationists was so weak that evolution continued to be taught in the schools.

One method to re-invigorate creationism would be to make it more scientifically palatable. The first item that had to go was the young earth part of creationism. The advent of radioisotope dating and advances in geology and cosmology made this view so untenable that no thinking person, and certainly no scientist, took it seriously. If the creationists were ever to have their views taught in our public schools that part of creationism had to go.

Enter Intelligent Design. Now it is agreed that the earth really is 4.6 billion years old as the radioisotope data clearly shows and yes, some aspects of Darwinism are correct. When pushed by environmental changes some natural selection and evolution can occur, but it is rarely able to actually account for the formation of new species. When some aspects of evolution are carefully examined, especially as related to certain structures and chemical pathways, they are claimed to be so complex and have so many critically interacting parts, that they could not possibly have evolved by the principals of Darwinian evolution. They had to have been the product of Intelligent Design. However, Intelligent Designers are very careful to never mention the word God—God forbid. This would make Intelligent Design sound too religious and this would keep it from being taught in schools as an alternative to the theory of evolution. Instead the Intelligent Design movement simply states that some force or power other than evolution was responsible. In addition, even though providing any testable hypotheses is vigorously avoided, and even though no papers on Intelligent Design have appeared in any of the peer-reviewed scientific literature, its proponents claimed that Intelligent Design is scientific and thus qualifies to be taught in the nation's schools. Finally, once that is accomplished, it is further proposed that any naturalistic scientific method that does not include the possibility of involvement of a divine force should be eliminated.

Our entire modern civilization exists as a result of naturalistic science and the application of the scientific method. This method consists of the generation of testable hypotheses and the dispassionate, unbiased testing of these hypotheses. Hypotheses that fail this process are discarded. Those that pass this process are accepted unless they are falsified by later studies. By contrast, Intelligent Design is not scientific because it does not use the scientific method. It is not dispassionate. It is not unbiased. It pre-judges the outcome and assumes that Intelligent Design is always the correct answer.

In its present incarnation, it appears that Intelligent Design's only enemy is the theory of evolution. However, the Wedge[3] philosophy is far broader than that. It

proposes to dismantle all naturalistic science. This clearly would be catastrophic for modern civilization. The best way to counter Intelligent Design is to provide the truth.

The previous chapters illustrate the fact that none of the anti-evolution complaints of Phillip Johnson [4-6] and none of the examples of so-called "irreducible complexity," described by Behe [7] are valid. All of Behe's examples are either reducible or modular or both. A wise man once said "Science moves funereally. Scientists don't change their minds, they just die off." This is often true of non-scientists as well. We all have complex reasons for believing what we believe and those beliefs are difficult to change regardless of rational evidence that suggests they are incorrect. In this respect, this book is not intended to change the mind of any members of the Intelligent Design group. This is unlikely to ever happen regardless of the evidence. This book is instead aimed toward those who the Intelligent Design creationists are attempting to target—non-scientists who need to see all the evidence before they make up their minds. In this book, I am proposing that it is possible for humans to maximally use both their rational and their spiritual brains. To maximize the use of the rational brain, the role for evolution is critical for helping us answer important questions such as, "Where did we come from?" I hope to have made the point that the theory of evolution is incredibly powerful and capable of answering these questions.

It has often been said that the theory of evolution is unscientific because it poses no testable hypothesis. Not every hypothesis in science can be tested in the laboratory. Darwin's theory of evolution poses a wide range of testable predictions. For example, one prediction is that more primitive forms of life should be found in older strata and the more developed forms in later strata. This has been validated in thousands of field studies and evidence to the contrary has never been found. Another prediction was posted by Darwin himself when he stated that in many cases where there appear to be no intermediate forms in the evolutionary process, it is a result of an incomplete fossil record that would eventually be filled in. This prediction has been validated many times. Another prediction is that if all the species on earth are descended from a common ancestor, they should all use the same genetic code. There are 1.4×10^{70} informationally equivalent possible genetic codes. [8] Despite this, all of the thousands of species with sequence data show they use the same genetic code. [9] This is just a small sample of the thousands of testable predictions all of which are consistent with the theory of evolution.

By contrast, Intelligent Design creationism fails to provide testable predictions. Although the founders of Intelligent Design have desperately sought to obtain even the slightest degree of scientific recognition, they have never specified anything that their theory predicts. As pointed out by Kenneth Miller, [10p123] Johnson has assiduously avoided putting into the record what the implications of Intelligent Design would be for the sequential character of the fossil record. In fact, when asked to present any predictions he refused. Miller pointed out that Johnson is a lawyer, not a scientist. Just as a defense attorney's job is to instill reasonable doubt so their client will not be convicted, Johnson's goal is to instill doubt about the theory of evolution as an excuse to teach creationism in schools, not come up with a predictive theory of his own.

While the Intelligent Design creationists need to develop a testable theory of their own in order to have legitimate entry to the marketplace of science, they also need to explain some of the weirdness of their position that a designer was responsible for the creation of living organisms. Miller put it well:

> Intelligent design advocates have to account for patterns in the designer's work that clearly gives the appearance of evolution. Is the designer being deceptive? Is there a reason why he can't get it right the first time? Is the designer, despite all his powers, a slow learner? He must be clever enough to design an African elephant, but apparently not so clever that he can do it the first time. Therefore we find the fossils of a couple dozen extinct "almost" elephants over the last few million years. What are these failed experiments, and why does the master designer need to drive so many of his masterpieces to extinction?
>
> Intelligent Design does a terrible disservice to God by casting him as a magician who periodically creates and creates and then creates again throughout the geological ages. Those who believe that the sole purpose of the Creator was the production of the human species must answer a simple question—not because I asked it, but because it is demanded by natural history itself. Why did this magician, in order to produce the contemporary world, find it necessary to create and destroy creatures, habitats, and ecosystems millions of times over? [10p127-128]

Elsewhere he states:

> They hobble His genius by demanding that the material of His creation ought not to be capable of generating complexity. They demean the breadth of His vision by ridiculing the notion that the materials of His world could have evolved into beings with intelligence and self-awareness. And they compel Him to descend from heaven into the factory floor by conscripting His labor into the design of each detail of each organism that graces the surface of our living planet. [10p268]

Behe, another major Intelligent Design advocate, has been less reluctant to suggest a testable hypothesis. He suggested that the designer placed in the first cell, from which all subsequent organisms evolved, all of the genes required for complex structures but in an inactive state just waiting to be activated when they were needed, often many millions of years later. This prediction is extremely easy to falsify by examining the DNA sequence of prokaryotes versus eukaryotes. Not only do prokaryotes have less total DNA, they have far fewer genes than vertebrates and mammals. In addition, this hypothesis violates Behe's own statements that "natural selection can only chose systems that are already working." [7p228] If a gene is inactive for millions of years before being called upon to function, it will not undergo natural

selection and will have accumulated so many deleterious mutations that it would cease to exist.

I have attempted to show in the prior chapters on evolution that none of the Intelligent Design arguments are valid. Since their focus is on complexity, I have focused on the most complex of the issues they have raised. Responses to any issues not covered in these chapters can be found on web sites such as the National Center for Science Education at www.ncseweb.org, evolution.berkeley.edu, www.talkorigins.org, and www.talkreason.org.

Is Darwinism Poison to Religion?

The source of much of the vitriol that both the Creationists and the Intelligent Design creationists displayed in trying to discredit evolution comes from the belief that it diminishes God and the teachings of Christianity. The literal Young Earth Creationists believe that if the account of creation in the Book of Genesis is falsified, then none of the teachings of the Bible can be believed. Apparently they have never heard of the use of metaphor as a powerful technique in literature. The Intelligent Design creationists have similar worries that if the job of creation is taken away from God, his role as Redeemer is somehow diminished. Both groups worry that if Darwinism is true then the whole moral fabric of humanity is somehow doomed. Do all Christians agree with these views? No. Robert Pennock put it well in his book, *Tower of Babel.* [11p39]

> Because almost all of the conflict that reaches the level of public debate involves creationists attacking evolution and scientists defending the same, most people have the erroneous, though understandable, view that this is just a battle between Fundamentalist Evangelicals and scientists, and do not recognize that many mainstream Christian theologians are equally involved in opposing creationism. They are appalled that creationists presume to limit the means by which God's creative power can operate and to claim that their anti-evolutionary view is the only true Christian viewpoint. Theologically they object to thinking of Genesis as giving a literal description of Creation as though it were a science textbook, and they caution us not to forget the notorious earlier "conflict" between the scientific and religious views about the movement of the earth and the heavens, and the aphorism that was the lesson of "the Galileo affair," namely that the Bible teaches how to go to heaven, not how heaven goes. Many mainline religions and Christian denominations have explicitly declared that they find no conflict with evolution.

A specific example is the statement of Pope John Paul II. In an October 22, 1996 message to the Pontifical Academy of Sciences, he explicitly endorsed the findings of evolutionary theory, stating that "fresh knowledge leads to recognition of the theory of evolution as more than just a hypothesis."

Judaism also has no issue with evolution. Rabbi Samson Raphael Hirsch (1808-1888), the great nineteenth-century Torah scholar, wrote that a totally naturalistic evolutionary explanation for life would show the "creative wisdom" of God in being able to design a set of simple rules that produces extraordinarily complex and rich results without any need for interference. Thus, neither mainstream Christian, Catholic, nor Jewish theologians believe that evolution is a threat to their religion.

The scientific method, what Johnson calls "scientific naturalism," is also no threat to religion. The scientific method cannot rule out a role for God as a causative agent in a given process; it simply does not start with the assumption that God is the cause. [11p202] The search for testable hypotheses comes first.

The point of the previous chapters is that the essence of science is to find truth by making and testing hypotheses. Hypotheses that fail this process are discarded. The hypotheses based on the theory of evolution have been validated over and over in thousands of studies. Intelligent Design creationists either provide no testable hypotheses or, for the one time they did, the hypothesis failed miserably. Intelligent Design is not a viable alternative to the theory of evolution. A belief in God and a belief in evolution are not mutually exclusive.

As pointed out in the introduction, the purpose of this book is to explore two fascinating capabilities of the human brain, the rational brain that seeks objective truth and the spiritual brain that seeks solace in spirituality and wants to be connected to something greater than itself. The past chapters were devoted to the conclusions that the rational brain would come to about the central question of "Where did we come from?" and "Who created us?"

Thus the purpose of Parts I and II was to provide information to counteract the assertions of the creationists that there are huge gaps in our knowledge about evolution and that these gaps can only be closed by divine intervention. While there will always be gaps in scientific knowledge, I hope to have shown that most of the gaps that matter have been filled in by modern science. The gaps are huge only if one chooses to avert one's eyes away from reality. If the listener is told only a biased viewpoint and does not have the background or expertise on which to base an informed decision, the decision will be a foregone conclusion—like a trial where only the prosecution gets to present its case. At a minimum, for those interested in listening, I hope I have provided the reader with a more balanced set of information on which to base a decision. Intelligent Design has not provided the correct answers. The theory of evolution, especially in its most modern versions, has.

Part III extends the discussion of "Where did we come from?" further back in time to the origins of the universe, to cosmology, to quantum theory, and quantum weirdness and its role in spirituality.

Part I of this book introduced some of the basic aspects of the theory of evolution. This has been attacked by the Intelligent Design neo-creationists as inadequate to answer some of the more difficult questions about complex systems and structures that have been claimed to have such irreducible complexity that a supreme being capable of Intelligent Design would have to have created them.

The chapters in Part II illustrate that none of the Intelligent Design creationist attempts to disprove the theory of evolution are valid. Good theories make testable predictions. For evolution, such predictions have been validated thousands of times. Most Intelligent Design creationists refuse to state testable predictions based on their theory. One testable theory proposed by Behe failed miserably. Intelligent Design is not a viable alternative to the theory of evolution.

As painful as it may be to some, life on earth and the development of all species of life on earth, can take place without divine intervention. Despite this, neither mainstream Christian, Catholic, nor Jewish theologians believe that evolution is a threat to their religion. Religions have no reason to fear evolution.

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Truth is more of a stranger than fiction.

Mark Twain

Part III

Cosmology

Who are we? Why are we here? Was our universe created from nothing? If so is this proof that God exists? Did time start with the creation of the universe or was it always there. Has the universe been created from intense concentrations of energy? If so where did that energy come from? Could only God have put it there? Is the energy itself God? These and many other questions have relevance to the issues of theology and cosmology—the study of the origin, composition and fate of the universe. Cosmology is thus very relevant to a book about *Who Created God?* and a book about our rational versus our spiritual brain.

Two of the most common reasons cited by theists and Intelligent Design proponents as evidence that God exists come from different aspects of cosmology. These relate to the Big Bang and the Anthropic Principle.

- The Big Bang suggests that the universe was created from nothing—in one gigantic explosive inflation. Can only God create something from nothing or do the laws of physics allow this to happen? Does quantum theory allow this to happen? Would the existence of multiple universes allow this to happen?
- The Anthropic Principle states that the universe, life and man would not exist unless all of the cosmological constants were precisely what they are. Can only God bring about such an incredible feat of fine-tuning or are there other equally valid explanations that avoid the even more difficult question of — Who created God?

Who created us? Where did we come from? This question was addressed in relation to the origin and evolution of life on earth in Parts I and II of this book. These parts showed that life is the product of evolution and natural selection for variations that were brought about by different types of random changes in DNA. While evolution is not directed, it does tend toward the development of greater and greater complexity. This is the result of the simple fact that when significant environmental changes occur, more complex organisms often have a selective advantage over organisms that have remained unchanged. Because the earth formed 4.6 billion years ago, this story is limited to that time span. The study of cosmology allows us to explore our origins back to the beginning of the universe—13.7 billion years ago.

The past century has seen a series of remarkable new discoveries in relation to the theory of relativity, quantum theory and string theory. Some of the weird aspects of these theories have stretched the boundaries of our rational brain and have opened up new boundaries for our spiritual brain. Does the weirdness of quantum theory suggest there are things in the universe that are greater than the sum of its parts, or do we simply need to expand our belief in the rational laws of nature to accommodate this weirdness? Is there anything in cosmology and the weirdness of quantum mechanics that can provide the rational brain with a sense of peace, spirituality and connectedness to the universe? Can the rational brain find God in cosmology or is that kind of God too cold and too impersonal? There is still much about the universe that science cannot yet explain. Is this reason for theists to rejoice? Is this reason for believing in God? Or, as has occurred many times before in science, will the unknowns soon become known?

The following chapters are not meant to be a definitive study of all the remarkable cosmological findings and theories that have developed in the past and current centuries. That would require several books. Instead I have focused on those concepts that I feel are most relevant to the essence of this book, the conflict between our rational and spiritual brain, and whether the recent advances in cosmology prove that God exists. The first four chapters of Part III provide a basic review of the science of cosmology. The last chapter discusses the implication of these subjects for theology, religion, the conflict between our rational and spiritual brain, and the issue of *Who Created God?*

Einstein said that if quantum mechanics were correct then the world would be crazy. Einstein was right – the world is crazy.

David Greenberger

Chapter 20

The Weird World of Quantum Physics

Several of the aspects of physics and cosmology that are relevant to the issue of God and spirituality revolve around some of the weirder aspects of quantum physics. Some of the weirdest of these relate to interference, the uncertainty principle, and entanglement.

Interference

Christiaan Huygens, a famous seventeenth century scientist, argued that light was propagated by waves. Just as sound required air for its propagation, he proposed that light was propagated by what he called ether. He proposed that ether was composed of tiny elastic particles which when excited produced light waves. Another, even more famous seventeenth century genius, scientist and mathematician, Isaac Newton, thought Huygens was wrong and proposed instead that light consisted of tiny particles. By traveling at different speeds these particles produced different colors of light. This was the beginning of a long running feud over the question of whether light was a wave or a particle.

The issue appeared to have been solved with the experiments of a brilliant British physician and physicist, Thomas Young. His greatest contributions to physics came from his double-slit studies of light demonstrating interference. If a light beam was shone through a single slit it produced a single bright band of light (Figure 1).

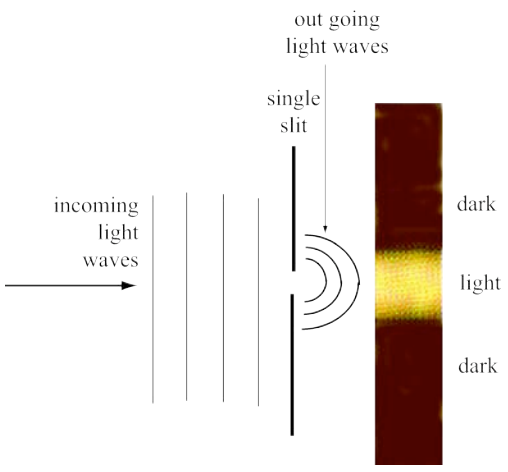

Figure 1. Single-slit experiment producing a single band of light on the detector.

In contrast, when light was shone through a double slit, an interference pattern of light and dark bands appeared on the detector (Figure 2).

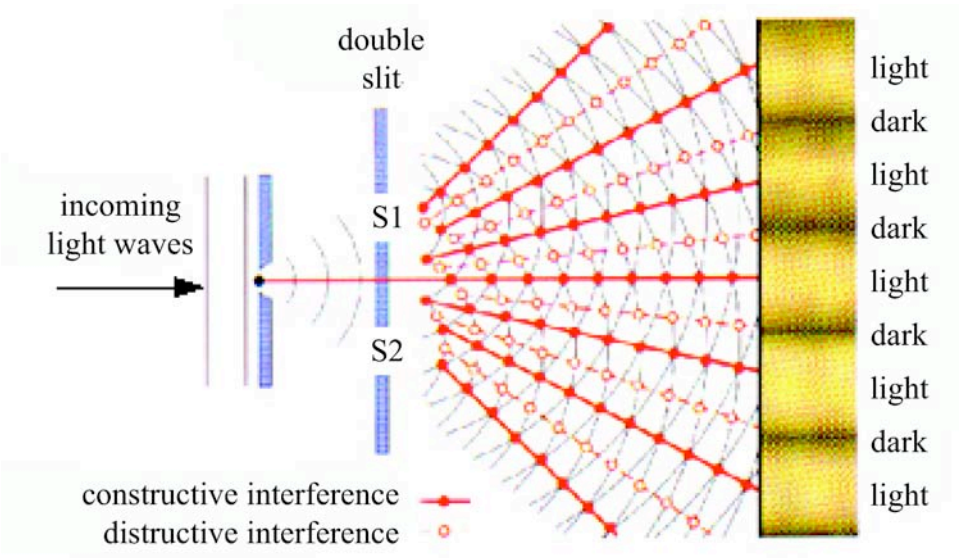

Figure 2. Double-slit experiment producing an interference pattern.

When the light passes through two slits the waves from each slit caused either constructive or destructive interference with the waves from the other slit. In constructive interference the amplitude peaks of the waves meet and the light signal is enhanced. In destructive interference, the troughs of the waves meet, the signal is canceled out and the light is diminished. This results in light and dark bands producing an interference pattern. Since such a pattern is explained by waves, Young proposed that his experiment proved that light is a wave. This theory held prominence for the next 100 years.

Planck's constant. Max Planck, a German physicist, initiated the field of quantum physics with his studies of energy. His doctoral dissertation was in the field of thermodynamics, or the study of the conservation of energy. He became interested in a phenomenon in physics known as *blackbody irradiation.* Thomas Wedgewood, the founder of the British Wedgewood porcelain, initiated the concept of blackbody irradiation. It had been known since ancient times that the hotter the object became, the more its color shifted from red to violet. During his work with porcelain kilns in 1792 Wedgewood discovered that the color of objects heated to a very high temperature depended only upon the temperature and not on other characteristics of the heated object.

A problem with blackbody irradiation was that at some temperatures the known physical laws relating to radiant energy broke down. He found that if he prevented one of the values in the equations from going all the way to zero, all of these problems disappeared. This minimum value was 6.626×10^{-34} Joule-seconds, a very, very tiny number. This was called Planck's constant, and the tiny packages of energy were

called *quanta*. The equation for the quantum energy of a photon was E = hf, where E was the energy of a photon, h was Planck's constant and f was the frequency of the radiation. This was called Planck's law. In essence Planck's law states that *radiant energy exists in discrete quanta* that are proportional to the wave frequency. The concept that energy occurred in discrete packets provided the beginnings of quantum theory and transformed the field of physics.

Around the turn of the twentieth century physicists began to write about the photoelectric effect of light. This referred to the ability of certain metals to produce electricity when light was shone on them. The wave theory of light predicted that A) the more intense the light the more energy the electrons would have when they fly off the metal plate, B) if the light was very feeble it would be necessary to expose the plate for several seconds or minutes until enough waves struck it to knock electrons loose, and C) waves of any frequency should knock electrons free.

Experiments showed that none of these predictions were true. The energy of the electrons did not depend on the intensity of the light, the electrons always appeared as soon as the light reached the plate, and no electrons were produced if the frequency of the light waves were below a critical value.

In Einstein's 1905 miracle year, in which he produced four groundbreaking papers, one was entitled "On a Heuristic Viewpoint Concerning the Production and Transformation of Light." [1] In this paper he stated:

> In accordance with the assumption to be considered here, the energy of a light ray spreading out from a point source is not continuously distributed over an increasing space, but consists of a finite number of energy quanta which are localized at points in space, which move without dividing, and which can only be produced and absorbed as complete units.

He utilized Max Planck's finite energy concept and proposed that the energy of the electrons did not depend upon the intensity of the light because each electron absorbs only one packet at a time. If the absorbed energy is large enough to expel the electron from the metal, it leaves. If not, the electron dissipates its energy in collisions with nearby electrons and atoms before it can absorb another packet. As soon as a single packet containing sufficient energy strikes the source plate, it will knock an electron free. There is no need to wait for multiple waves to build up enough energy. Importantly, Einstein also predicted that no electrons are produced if the frequency of the light waves is below a critical value, and that the maximum energy of ejected electrons should increase with the frequency of the applied light. The photoelectric effect is diagrammed in Figure 3.

Einstein's work was consistent with both the particle and the wave theories of light. Subsequent experiments proved that Einstein's photoelectric theory was correct. The packets of light were later termed photons. Although the paper on the theory of relativity, for which Einstein is most famous, was published in the same issue as the

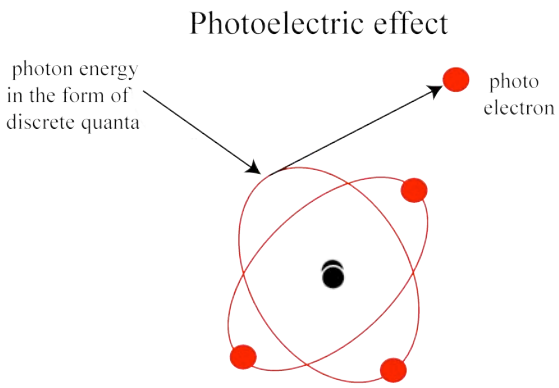

Figure 3. Photoelectric effect.

paper about the photoelectric effect, it was the photoelectric effect paper that won him the Nobel Prize. In 1924 the French physicist Louis de Broglie proposed that in addition to light packets, physical bodies such as electrons and other particles also had wave properties.

So where is the weirdness? So far, nothing is particularly weird about what has been described. The weirdness came when Young's experiments were repeated using light that was so weak that it emitted only one photon at a time. Now our rational brains would say that the interference pattern would no longer be produced because a single photon obviously cannot interfere with itself. If it did, the photon would have to pass through both slits at the same time. Since a particle cannot be in two places at the same time, this should be impossible and the interference should disappear. The remarkable thing was that the interference pattern did not disappear. It was still present, as shown in Figure 4.

In quantum physics, this phenomenon of appearing to be in two places at the same time is called the principle of the *superimposition of states.* I will refer to the strange parts of quantum theory and quantum weirdness.

<u>Quantum weirdness #1:</u> When interference experiments are performed with a light intensity so low that only one photon is emitted at a time, the interference pattern is still present. This is the principle of the superimposition of states. This indicates a particle can be in two places at the same time.

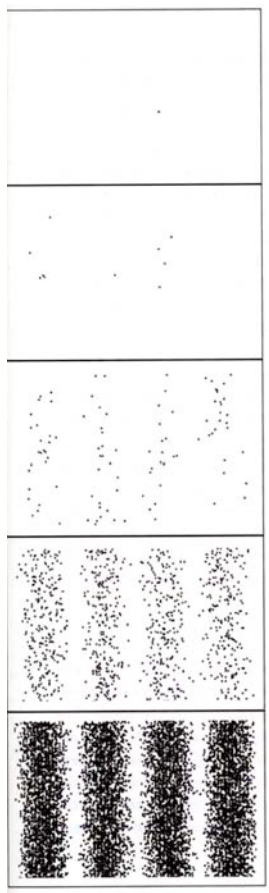

Figure 4. Results of sending one photon at a time through the double slit. The five panels show the results for 1, 10, 100, 1,000 and 10,000 photons. Each panel includes the results of the previous panel. [7]

Some authors have brought different aspects of the weirdness of quantum physics into discussions of God and spirituality. However, to evaluate the spirituality issue it is important to determine the maximum size of the particles that are served by quantum laws. Studies of interference are

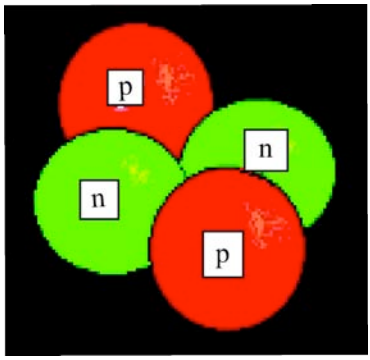

Figure 5. Alpha particle (helium nucleus) consisting of two protons and two neutrons.

Figure 6. A buckyball. [8]

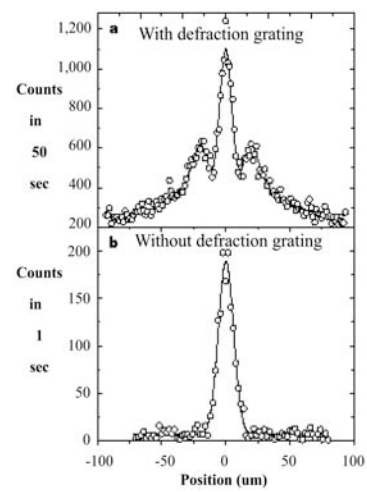

Figure 7. Demonstration of interference using a stream of buckyballs. A) With diffraction grating. B) Without diffraction grating. Arndt et al. Wave-particle duality of C60 molecules. *Reprinted by permission from Macmillan Publishers, Ltd.* Nature. *401: 680-681, 1999.*

valuable in this regard. De Broglie predicted that—in addition to photons, electrons, neutrons—alpha particles and a wide range of other particles would also show a wave pattern. If so, they should also show interference, and they do. Figure 5 shows an alpha particle consisting of a helium nucleus with two protons with a positive charge, and two neutrons with no charge.

An alpha particle is much larger than a photon or an electron and it showed interference. What is the maximum-size particle that shows interference? This prize goes to buckyballs. A buckeyball is a molecule consisting of 60 carbon atoms arranged in a structure resembling a geodesic dome (Figure 6).

Buckyballs are named after Buckminster Fuller, who made such domes famous in architecture. In 1999 Arndt and colleagues [2] demonstrated wave-particle duality and interference with buckyballs consisting of 60 carbon atoms (Figure 7).

They showed that a stream of buckyballs passing through a diffraction grating produced an interference pattern that was not present when the diffraction grating was removed. The presence of the diffraction grating interactions at the wave troughs resulted in destructive interference-producing dips on both sides of the main peak.

The Uncertainty Principle

When light is shined through a prism, or through water droplets in a rainstorm, a beautiful spectrum of colors is produced. It had long been known that lines of different wavelengths appeared in the spectra produced when the source of light was a hot gas. Different elements produced different spectral lines as shown in Figure 8.

There are three types of spectra emitted by objects. The one we experience when we see a rainbow or pass light through a prism is a continuous spectrum. It does not contain spectral lines. With an emission spectrum, hot gases of various compositions produce the spectral lines as shown in Figure 8. An absorption spectrum is produced when a continuous spectrum passes

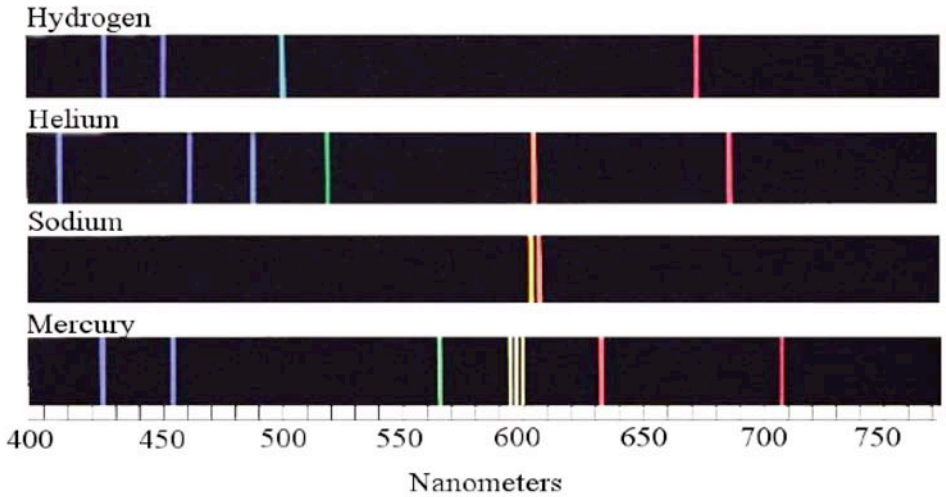

Figure 8. Spectral lines typical of different elements. [9]

through a cool gas. Here the spectral lines are removed, producing an inverse of the emission spectrum. These three types of spectra are illustrated in Figure 9.

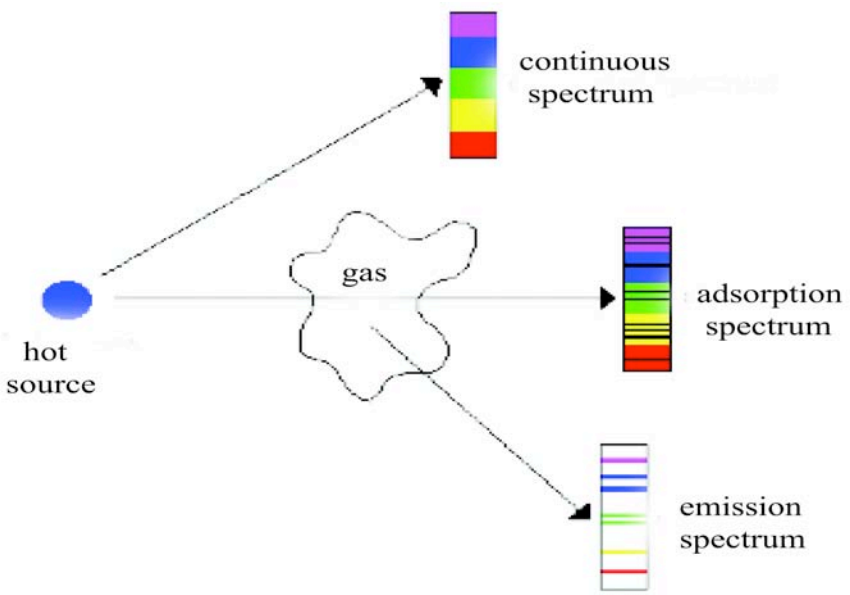

Figure 9. Three types of spectra.

The simplest atom is hydrogen, consisting of a nucleus with one proton orbited by one electron. A number of scientists described different frequencies at which the hydrogen atom produced different sets of spectra. These sets were named after the scientists who described them—Lyman for an ultraviolet series, Balmer for a visible light series, and Paschen for an infrared series. No one had an adequate explanation

of what was producing these different, very specific spectra. No one, that is, until a Danish theoretical physicist, Niels Bohr addressed the problem.

Using Max Planck's theory as a basis, he quantized the energy of the atom and proposed that when the hydrogen atom drops from one energy level to a lower one, the energy that is released comes out as a single Einstein photon. This use of Planck's quantum theory to explain what happened in the interior of an atom was a major breakthrough for physics and further expanded quantum theory. It also finally explained spectral lines. *Every emitted frequency was due to an electron descending from one energy level to another.* The difference between the beginning and ending energies was emitted in the form of a quantum of energy. [3p43] This concept is illustrated in Figure 10.

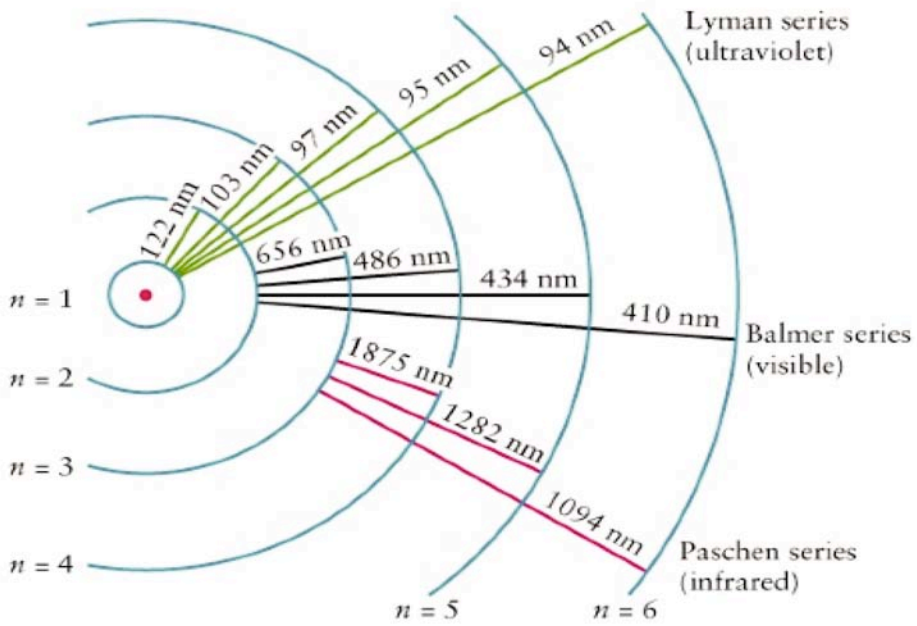

Figure 10. Diagram of how Niels Bohr's quantum theory of the atom explains the Lyman, Balmer and Paschen series of spectral lines. [10]

Each orbital drop produces a quantum packet of energy radiation resulting in lines with specific frequencies. In 1922 Niels Bohr received the Nobel Prize for his quantum theory of the atom. The story is told that following a discussion of Young's dual slit experiment and the principle of the superimposition of states, Bohr murmured, "To be…to be…what does it mean to be." [3p88]

Schrödinger's equation. Erwin Schrödinger was a professor of Theoretical Physics at the University of Zürich. He was anxious to make a major contribution to the field of physics. His colleagues such as Einstein and Bohr had made their groundbreaking discoveries in their early twenties, yet by age 37 Schrödinger had not produced anything outstanding. Although married, he was well known for keeping old girlfriends in his life. A few days before Christmas in 1925, he left for a vacation in a

villa in the Alps. Although his wife did not join him, an unknown old girlfriend did. According to legend, the erotic tryst jarred his creative insights and he authored what is known as the *Schrödinger equation.* [3p62] It describes the statistical behavior of particles in the tiny world of quantum mechanics.

His equation had two important consequences. The first relates to statistical probabilities. In the macro world that we can see, if the initial location *(position)* and speed of a car *(momentum)* is known, it is possible to predict with great accuracy where the car will be at a given future time. By contrast, in the micro world of the atom, *it is only possible to describe a range of probabilities about where a particle will be.* The second consequence relates to entanglement and will be discussed later. In 1933 Schrödinger received the Nobel Prize for his famous equation.

Heisenberg's uncertainty principle. Werner Karl Heisenberg, using a form of mathematics called *matrix mechanics,* further expanded the issue of probabilities. The uncertainty principle states that in the subatomic quantum world, the position and momentum cannot both be accurately known. The more precisely the position is known, the more uncertain the momentum. The more precisely the momentum is known, the more uncertain the position. In other words, uncertainty cannot be removed from quantum systems. In 1932 Heisenberg received the Nobel Prize for his contributions to quantum theory. The uncertainty principle provides our second quantum weirdness.

> **Quantum weirdness #2: In the macro world that we can see, precise knowledge about position and momentum allows us to accurately calculate a new position. However, in the micro world of quantum mechanics, the more precisely position is known, the more imprecise our knowledge of momentum, or the more precisely momentum is known, the more imprecise our knowledge of position. This is known as *Heisenberg's uncertainty principle.***

Entanglement

While Einstein played a major role in the development of quantum theory, he was always uncomfortable with it as indicated by his famous statement, "God does not play dice." By this he meant chance should have no place within the laws of nature. While in the quantum world reality was always stated in probabilities or chance, he felt that a better or deeper theory would allow precise predictions rather than only probabilities. In this regard, he and two colleagues, Podolsky and Rosen, issued a challenge to the field of quantum physics, claiming it was incomplete. This was reflected in the title of their 1935 paper, "Can Quantum-Mechanical Description of Physical Reality be Considered Complete?" Based on the initials of its authors, Einstein, Podolsky, and Rosen, this is often referred to as the EPR paper.

They described what occurs when an atom gives off two photons in response to one of its electrons descending to a lower state of energy. While neither photon flies off in a definite direction, the pair will always be found on opposite sides of the atom.

That is, they leave the atom in opposite directions. These two photons are always intertwined. *The instant that one photon is changed, its twin—wherever it may be in the universe—will change instantaneously.* [3] This has been referred to as *entanglement,* a term coined by Schrödinger. In 2001, Amir Aczel published a delightful book on the subject. [3] He considered entanglement to be *the most bizarre of all the weird aspects of quantum theory.* Einstein termed this "spooky at a distance." The point that Einstein, Podolsky, and Rosen were trying to make with this thought experiment was that if quantum physics allowed such a bizarre phenomena to exist, then there must be something wrong with the theory.

Bell's Theorem. John Bell was a nuclear physicist whose day job was to design accelerators at European Center for Nuclear Research (CERN). He pondered the mysteries of quantum physics at night. He attacked the problem raised by the EPR paper. First a definition: *locality* refers to the concept that what happens in one place cannot instantaneously affect what happens at a distant location. That is, effects are local and do not occur at a distance. The issue of the EPR paper was that quantum theory and locality could not both be right. Einstein and John von Neumann felt that if particles appeared to be connected at a distance it was because there were *hidden variables* that conveyed how they should behave after they became separated, and the apparent non-locality was an illusion. If locality was truly correct, quantum theory was incorrect.

In its simplest form, Bell's theorem stated that if his equations, known as inequalities, could be violated by experimental results, this would provide evidence in favor of quantum mechanics and against the EPR complaints. In another paper, Bell proved that the hidden variables that Einstein and von Neumann assumed existed and would prove quantum mechanics was incomplete—did not exist. In summary, Bell's theorem was that *hidden variables* and *locality* had no place in quantum theory. Concerning Bell's Theorem, Aczel quotes a friend, Abner Shimony: [3p147]

> Bell was a unique individual. He was curious, tenacious, and courageous. He had a stronger character than all of them. He took on John von Neumann—one of the most famous mathematicians of the century—and with no hesitation showed that von Neumann's assumption was wrong. Then he took on Einstein.

Bell's theorem provided guidance to experimental physicists about how they could prove whether entanglement really existed. Many subsequent experiments proved entanglement and non-locality were real. [3] Instead of spelling a death knell to quantum theory, these experiments overwhelmingly supported it.

Quantum weirdness #3: When paired particles are emitted from an atomic source in opposite directions, their characteristics are entangled. When a property of one particle, such as spin, is changed, its twin will change instantaneously regardless of how far apart they are in the universe.

Entanglement and separation in space. Since distance has no meaning to entangled particles, entanglement would seem to break down our notion of spatial separation. However, if information cannot be transmitted, this connectedness across space and the universe has no meaning outside of the weird-world of quantum physics. Why can't entanglement transmit information? It all has to do with the role of the observer.

Role of the observer. In an extension of one of the experimental tests of entanglement, Yanhua Shih of the University of Maryland noted that when he could observe which of two paths were taken by a photon, no interference pattern was produced. In this "which-path" design, light acts as a particle. If he could not observe which of two paths was taken by a photon, it was a "both-paths" design. Now the photon was viewed as taking both paths simultaneously and an interference pattern was observed. This means that when not observed, the particle can take both paths at once, but as soon as the particle is observed or measured, "we force some quantum system to choose an actual value, thus leaping out of the quantum fuzz into a specific space." [3p251]

Quantum weirdness #4: Whether light acts as a wave or a particle depends on the observer. If the experiment allows one to determine which of two paths the photons take, light acts as a particle. If the experiment does not allow one to determine which of two paths are taken, the light takes both paths simultaneously and acts as a wave—and shows interference. The observer forces the quantum world to chose a specific value.

The implication of this is that as soon as information is extracted from the system it collapses. Since the observer cannot choose what that state will be, only random information is obtained, unsuitable for transmission.

Entanglement and the speed of light. The phrase, "Its twin will change instantaneously regardless of how far apart they are in the universe," carries with it an apparent violation of Einstein's theory of relativity that states that nothing can travel faster than the speed of light. In an experiment designed to examine this issue, Anton Zeilinger performed an entanglement experiment in Switzerland using 16 miles of fiber optics. In this experiment, if there was a signal from one end informing the other end of its status, it would have had to travel ten million times the speed of light. [3p237] However, since entanglement does not allow us to send readable messages, it does not violate the speed of light limitation.

Despite the above caveats, some physicists still believe that "the spirit of relativity theory" has been violated since "something" travels infinitely fast between the two particles [3p252]. John Bell himself was of this opinion. One way out of this messy weirdness is to take the view that nothing is really transmitted between two parts because the parts are actually not separate entities. They are a single entity.

Do deeper principles underlie quantum uncertainty and nonlocality? The interpretation that once the path of a particle is observed, interference collapses, is called the *Copenhagen Interpretation* of quantum weirdness. The fact that this is still an issue

is indicated by the fact that in its 125th anniversary issue, *Science* magazine asked scientists around the world what they thought were the major unanswered questions in science. One of the responses was, *Do deeper principles underlie quantum uncertainty and nonlocality?*[4] In addition to the Copenhagen Interpretation, one of the alternative explanations is the "many worlds" proposal. This suggests that interference, entanglements and other quantum phenomena are explained by posing that every possible quantum outcome really exists but in worlds parallel to our own. I personally am not convinced that this model is any less weird than the Copenhagen Interpretation.

Gravity and quantum weirdness—Do all objects occur in two places at once? Sir Roger Penrose at Oxford's Mathematical Institute has proposed a believable third interpretation. He is the author of *The Road to Reality: A Complete Guide to the Laws of the Universe.*[5] He pointed out that gravity is the only force physicists have been unable to explain in quantum terms. This is due in a large part to the fact that the force of gravity is by far the weakest of all the forces. It is so weak that theorists saw no problem with leaving it out of their equations. Penrose thinks this was a mistake. He points out that despite the tiny size of electrons, protons, and other particles that populate the quantum world, they also produce a warp in time and space, as Einstein proposed in his explanation of gravity.

If all objects can occur in two places at the same time, each would create its own distortions in space-time yielding two superimposed gravitational fields. It takes energy to sustain such a system, and the more energy required, the more unstable the system. Over time the unstable system settles back to its simplest, lowest energy state of one object in one place.[6] Tiny subatomic particles of the quantum world require so little energy they can persist in this unstable state forever. By contrast, bigger objects, like us, instantly settle into one state or the other. Penrose calculated that for a person, the time it takes to settle into one state is a trillionth of a trillionth of a second, too small to measure.

The beauty of this hypothesis is that it is testable. In addition, it removes some of the weirdness from the quantum world. There is nothing weird about the one force we all experience directly—gravity.

Is Quantum Weirdness Relevant to Human Spirituality?

One important question is, where does the boundary lie that separates the macro-world we see from the micro-world of quantum mechanics? If the boundary is too far into the micro-world, quantum weirdness would probably have no relevance to human behavior and experience. If the boundary encroaches on the macro-world, it may have relevance to human consciousness, thought, behavior, and a connectedness to something greater than us.

- Although Einstein complained about quantum weirdness by stating, "God does not play dice," Niels Bohr said, "Albert, stop telling God what he can do." Even more relevant to quantum weirdness, Stephen Hawking said, "God not only plays dice. He sometimes throws them where they cannot be seen."
- Does interference, and with it the idea that particles can be in two places at the

same time, have any relevance to Bohr's questions, "What does it mean to be?"?

- Should the uncertainty principle be viewed as one more reason, like evolution, to feel that we are just the probabilistic product of random events? Does that diminish us? Does that affect the question, "Do we have a purpose?" Does entanglement suggest that all humans are connected to each other and to nature, as the Eastern religions suggest, or is it just an interesting but irrelevant phenomenon since entanglement does not allow the transmission of information?
- Does the fact that certain aspects of quantum theory seem beyond human understanding allow our rational brain to more easily accept the concept of God—another concept beyond our understanding? Or should we behave as one scientist said to a colleague who didn't understand quantum weirdness, "Just shut up and do the calculations"?

One complaint of theologians and Intelligent Designers is that science does not include divine intervention as one of its primary hypotheses. Naturalistic science carries with it the implication of "That is all there is?" and "There is nothing here that is greater than the sum of its parts." Since supernatural beings are, by definition, greater than the sum of their parts, naturalistic science would seem to deny the existence of God. Many scientists agree with this, but not all. If there is any place in nature that God is hiding, or anywhere that the rational brain may feel comfortable with the thought that there may be something out there that is greater than the sum of its parts, the weirdness of quantum physics might be a reasonable place to go looking. However, if Penrose is right about the role of gravity, much of the weirdness disappears and with it many of these issues.

I have discussed the basic facts of quantum theory in some detail so the readers can have a firm background on what quantum mechanics is all about and can form their own opinions about whether quantum weirdness plays any role in their own spirituality. The above questions are just some brief teasers. Since many additional aspects of cosmology such as the Big Bang and string theory are relevant to religion, theology, and spirituality, a more complete discussion of the relevance of cosmology to these issues and to the potential conflict between our rational and spiritual brain is presented in Chapter 24.

A complete discussion of the relevance of quantum theory to spirituality is given in Chapter 24.

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Chapter 21

The Big Bang

The Big Bang theory proposes that the universe suddenly arose from virtually nothing. It has been seized upon by theists as one of the "proofs" that God exists. This is based on their assumption that only God can make something out of nothing. Since such theological importance has been placed on the Big Bang, I will provide the reader with enough detail to allow them to understand what the Big Bang is, how the theory originated, and what was involved at the level of subatomic particles – so you can make your own judgments.

One of the four papers that Einstein wrote in his 1905 "miracle year" was entitled "On the Electrodynamics of Moving Bodies." This was his paper detailing the special theory of relativity. A second very short paper published later in the same year was entitled "Does the Inertia of a Body Depend on Its Energy Content?" These papers changed forever how physicists viewed time and space. In the latter paper Einstein wrote: [1p35]

> If a body gives off the energy E in the form of radiation, its mass diminishes by E/c^2…The mass of a body is a measure of its energy content; if the energy changes by E, the mass changes in the same sense.

A simple rearrangement of this statement leads to the most famous equation in all of science: $E = mc^2$ where c^2 is the velocity of light squared. Since the velocity of light is very fast, 186,000 miles per second, when squared it produces a very large number. Thus, each unit of converted mass produces a huge amount of energy. We are most familiar with the implications this equation has for atomic energy where the conversion of tiny amounts of mass can produce enormous amounts of energy. However, the flip side of this equation provides great insights into the origin of the universe, since it shows that huge amounts of pure energy can be converted into mass. This is exactly what produced the universe—a quantum instability in huge amounts of energy started the development of the universe. This has been referred to as the *Big Bang.* This chapter is the story of that conversion of energy to mass. To better understand the story of where the universe came from, we must first review the building blocks of the current universe.

The Forces of the Universe

When Einstein wrote these papers only two types of physical forces were known:

gravitational force and electromagnetic force. We are all familiar with the force of gravity first proposed by Isaac Newton in 1867. It is what made the apple drop and what is responsible for the fact that our legs are always just long enough to reach the ground. We are also well aware of the electromagnetic force. This is responsible for electricity that runs our computers and telephones, for visible light that allows us to see, and for TV and radio waves that allow us to watch TV and listen to the radio. Figure 1 illustrates the different parts of the electromagnetic (EMF) spectrum.

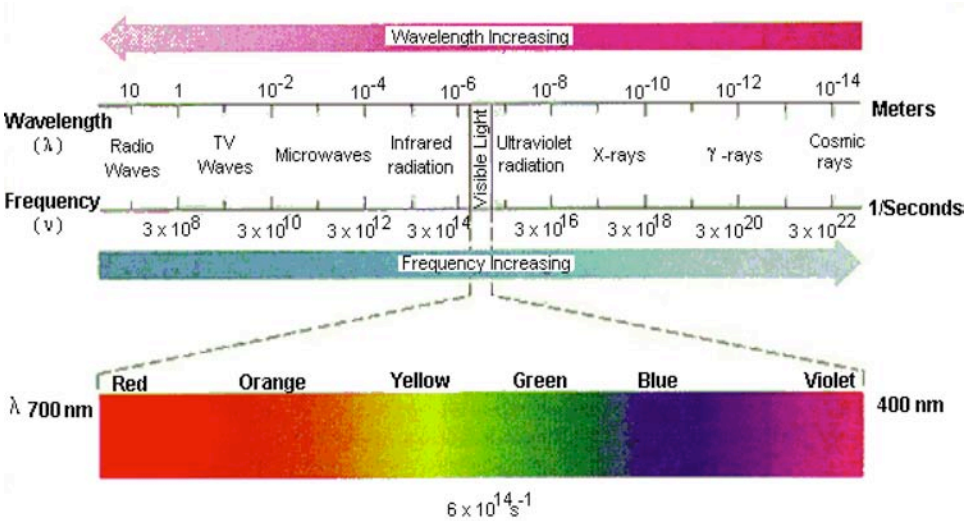

Figure 1. The range of the electromagnetic spectrum.[4] *Reprinted with permission of John Wiley & Sons, Inc.*

The visible light portion represents only a small part of the entire EMF spectrum. All of the different waves are composed of photons of different energy levels — the shorter the wavelength, the higher the frequency, and the greater the energy of the photons. The microwave portion of the spectrum is especially relevant to the story of the Big Bang. Although they are called microwaves, their wavelength is longer and they contain lower-energy photons than visible light. They are micro only in relation to radio and TV waves.

Einstein spent his remaining years attempting to develop a theory of everything that would unite the macro-world that his theory of relativity so well described and the micro-world of quantum mechanics, that he found so spooky and difficult to accept. However, he attempted to develop this theory without knowing about the two other forces of the universe, the strong force and the weak force. These were only discovered in the latter part of the twentieth century using powerful linear accelerators and are the nuclear forces of the subatomic world. The strong force is responsible for holding or gluing together the protons and neutrons of atomic nuclei. Without this force all matter would fly apart and we would not be here to discuss these forces. The weak force is responsible for the radioactive decay of elements such a uranium and cobalt.

Each of these forces is associated with a particle that represents the smallest

possible unit of that force. These forces and their characteristics are listed as follows:

Force	**Strength**	**Range (m)**	**Force Particle**	**Mass**
strong	1	10^{-15}	gluon	0
electromagnetic	1/137	infinite	photon	0
weak	10^{-6}	10^{-16}	weak-gauge bosons	86, 97
gravity	6×10^{-39}	infinite	graviton	0

This shows how weak the gravitational force is compared to the other forces. The range of the strong force is equivalent to that of a medium-sized nucleus, while that of the weak force is that of a proton. All of these force particles have zero mass except the weak-gauge bosons that have a mass equivalent to 86 and 97 protons. All have been experimentally proven except the graviton, which is being vigorously pursued.

Particles of the Universe

In addition to forces, the second major components of the current universe are the fundamental particles. The term *atom* dates to the time of Democritus (460-370 B.C.) the ancient Greek philosopher. He used the term to define the smallest, uncuttable particle of nature. When nineteenth century scientists identified pure compounds such as oxygen, nitrogen and carbon, the smallest units were called atoms. The British physicist J. J. Thomson at the Cavendish Laboratory in England discovered the first subatomic particle in 1897. He was experimenting with cathode ray tubes. It was known for years that when a high voltage of electricity was passed through a vacuum tube, the tube glowed with beautiful colors. It was assumed that some type of ray was being produced, but the composition of the ray was unknown. Thomson made the bold prediction that these rays were composed of "corpuscles" that resided inside the atom and that all atoms were composed of these corpuscles. Further work showed the Thomson's corpuscles were tiny, negatively charged particles. They were called *electrons.*

After the discovery of the electron, it was realized that there must be a positive charge in the atom to balance the negative charge of the orbiting electrons. It was assumed that the electrons and positive particles were evenly distributed throughout the mass of the atom. Ernest Rutherford was a student of Thompson. He was researching the newly discovered phenomenon of radioactivity using uranium. In 1898 he confirmed an earlier observation of Henri Becquerel that the radioactive rays coming from uranium consisted of two parts that he termed *alpha* and *beta.* Alpha rays were easily adsorbed while beta rays were more penetrating. Rutherford used the same technique that Thompson had used in his discovery of the electron to measure the charge of alpha particles. He found that if the alpha particles were passed through a thin sheet of mica, the image on a photographic plate was blurred. This did not happen if the mica film was not present. He termed this effect *alpha scattering.*

In further studies of alpha scattering with two colleagues Hans Geiger and Ernest Marsden, Rutherford found that when a gold film was used instead of mica, the alpha particles scattered at a much greater angle and sometimes *bounced straight backward.*

He described this as the most incredible event in his life, "as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you." Such huge deflections were not consistent with Thompson's model of the atom. They could only be explained if all the positive charges of the gold atom were concentrated into a tiny mass capable of causing the alpha particles to bounce backward. In 1911 Rutherford proposed that the atom contained a massive nucleus that contained all of the positive charge, and that the lighter electrons were outside this nucleus. This nucleus had to have a radius that was 10,000 times smaller than the radius of the atom. As described in the previous chapter, in 1915 Niels Bohr further refined Rutherford's model by suggesting the electrons also existed as quanta and occurred in orbits at different distances from the nucleus. In 1919 Rutherford first termed the positively charged particle in the nucleus a *proton.*

It soon became clear that the story of the composition of the nucleus was still not complete. Things did not add up. The charge of atoms reflected the number of electrons and protons. However, except for hydrogen they did not add up to the total atomic mass. For example, helium has an atomic mass of four but a charge of only two. Rutherford suggested that one solution would be the presence of a nuclear particle with no charge. He termed this a *neutron* but it was only a hypothetical concept. Again using radioactivity, in 1932 James Chadwick identified the neutron and showed that its mass was approximately 0.1 percent greater than the mass of a proton. When Heisenberg showed that the neutron could not simply be a protein-electron pair, it was clear that the third subatomic particle had been found. Figure 2 illustrates these three components of the atom.

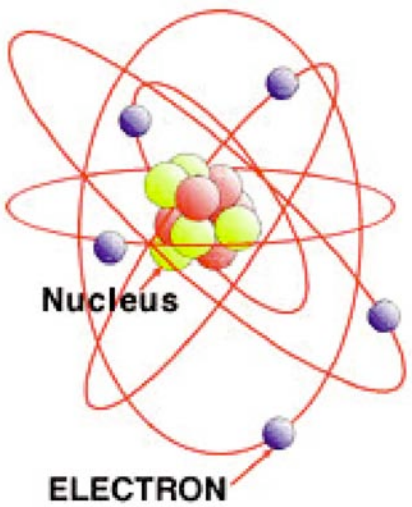

Figure 2. Structure of the atom. Yellow = neutrons. Red = protons. [5]

The following table summarizes these three particles, their charge and mass in atomic mass units.

Particle	**Symbol**	**Charge**	**Mass**
electron	e-	-1	0.000548
proton	p+	+1	1.007276
neutron	no	0	1.008665

The fourth subatomic particle to be proposed and then discovered was the *neutrino.* In 1930 Wolfgang Pauli predicted the presence of the neutrino based on the

need to explain aspects of beta radiation. The name *neutrino,* or *little neutron,* was proposed by Enrico Fermi to distinguish it from heavy neutrons. In the 1950s, using a nuclear reactor and a 400-liter tank of water and cadmium chloride, Frederick Reines and Clyde Cowan proved that neutrinos existed. The task was not easy because neutrinos can pass unaffected through a trillion tons of lead. Initially it was proposed to have no mass. Subsequently three types of neutrino were found each with a small but different mass (see Table below).

In the late 1930s *muons* were discovered in the course of studies of cosmic rays. They were the size of electrons but 200 times heavier. Brian Greene commented: [2p8]

> Because there was nothing in the cosmic order, no unsolved puzzle, no tailor-made niche, that necessitated the muon's existence, the Nobel Prize-winning particle physicist Isidor Isaac Rabi greeted the discovery of the muon with a less than enthusiastic, "Who ordered that?"

The theoretical physicist, Murray Gell-Mann, hypothesized that protons and neutrons were composed of three sub-sub particles. He termed these *quarks* after the whimsical name in James Joyce's *Finnegan's Wake.* In 1968 experiments at the Stanford Linear Accelerator showed that quarks were real. Each of the three types came in two varieties, *up* and *down.* Protons consisted of two up-quarks and a down-quark, while neutrons consisted of two down-quarks and one up-quark.

Further studies showed that all these particles were present in three families. Each family contained an electron or electron-like particle, one of three neutrinos, and two quarks—each of increasing mass. These are summarized in the following table where the mass is in multiples of the mass of a proton. [2p9]

Families of Fundamental Particles

Family 1		Family 2		Family 3	
Particle	**Mass**	**Particle**	**Mass**	**Particle**	**Mass**
Electron	.00054	Muon	11	Tau	1.9
Electron-neutrino	$<10^{-8}$	Muon-neutrino	<.0003	Tau-neutrino	<.033
Up-quark	.0047	Charm-quark	1.6	Top-quark	189
Down-quark	.0074	Strange-quark	.16	Bottom-quark	5.2

The final set of fundamental particles consists of antimatter particles for each of the above matter particles. These then are the players for understanding the components of the particle soup involved in the Big Bang. What about the theory of the Big Bang itself?

History of the Big Bang

In 1923, Edwin Powell Hubble discovered Cepheid variable stars in the Andromeda galaxy. Because of their properites they act as a "standard candle" and can provide accurate estimates of distance. This allowed Hubble to show for the first time that galaxies existed beyond our own galaxy, the Milky Way. In 1929 he announced,

what has come to be called *Hubble's law,* that the galaxies are moving apart at a rate that increases with their distance. In other words, *the universe is expanding.* This observation was based on the fact that when galaxies are rapidly receding the light waves are longer and redder. This remarkable finding that the universe was expanding carried with it the implication that the *universe had a finite start.*

While Einstein had proposed that the size of the universe was constant, in 1922 a Russian mathematician, Alexander Friedman, argued that it was possible for the average density and radius of the universe to change over time, a theory that Hubble proved to be true. Einstein's equations were extremely difficult and complex. Friedman made a few simplifying assumptions that bypassed these equations. Now the solution to the equations depended on just three variables: H, the rate of expansion of the universe (Hubble's constant); *omega*, the average density of matter in the universe; and *lambda,* Einstein's cosmological constant.

In 1933, Belgian priest Georges Edouard Lamaître published a paper, "Discussion on the Evolution of the Universe." In it he suggested the expansion that Hubble described started by an initial explosion. He visualized a "primal atom" of incredible density containing all of the material for the universe in a sphere 30 times larger than the sun. This explosion sent matter off in all directions resulting in the expansion of the galaxies. In 1946 he expanded on this theory in his *Hypothesis of the Primal Atom.* In more poetic terms he wrote:

> The evolution of the world can be compared to a display of fireworks that has just ended: some few red wisps, ashes and smoke. Standing on a well-chilled cinder, we see the slow fading of the suns, and we try to recall the vanished brilliance of the origin of worlds. [3p51]

Background Micro-Radiation

In the 1940s George Gamow, a nuclear physicist, began to put the conditions for the early universe on a more formal and scientific footing. Like a paleontologist exploring ancient evolution by studying fossils, he sought out the "fossils" of the ancient universe. He proposed that Lamaître's primal atom was *an intense concentration of pure energy.* Einstein's famous equation allowed this energy to be the source of the matter in the universe. In 1948 his former student Ralph Alpher and a colleague, Robert Herman, published a famous paper entitled the "Origin of Chemical Elements." Using Einstein's equations they turned back the cosmic clock to the beginning of the universe. As the radius of the universe decreased, the temperature increased to the point that all of the particles and forces listed above were fused. From this starting point they calculated that the Cosmic Background Radiation (CBR) today should have a temperature of 5 degrees Kelvin. Kelvin degrees start at absolute zero, which is equivalent to -459°F.

At that time there was no way to measure CBR. This soon changed, almost by accident. Arno Penzias and Robert Wilson of the Bell Telephone Labs in New Jersey were interested in microwaves. These were very difficult to detect, but Bell Labs had

a large horn-shaped antenna that could detect them. Bell Labs was interested in microwaves as a possible new mode of communication. Penzias and Wilson were attempting to determine the signal to noise ratio of microwaves. The noise part seemed to come from every direction above the horizon and did not change with time. They published their results in 1965 in the *Astrophysical Journal,* discussing it as a problem of "excess antenna temperature." It was quickly realized by others that this represented the CBR that Gamow, Alpher, and Herman had proposed. The background temperature was 2.7°K, remarkably close to what had been predicted. This was the first proof that what Fred Hoyle had called the Big Bang was true. It is perhaps worthy of note that purists point out the Big Bang was neither big nor a bang. The initial singularity was vanishingly small, and since there was no air there was no noise. However, any explosion that produces the entire universe certainly deserves the name "Big."

The first map of CBR was performed by NASA's **CO**smic **B**ackground **E**xplorer **D**ifferential **M**icrowave **R**adiometer (COBE DMR). The results made worldwide front-page news on April 24, 1992. The map showed the universe when it was 300,000 years old. The pattern showed an extremely uniform background radiation, but not totally uniform. The uncertainty principle states that the universe could not be perfectly smooth. Variations of one part in 100,000 were found. This was consistent with the predictions of quantum theory. The larger hot spots indicated where gravity would overcome expansion enough to allow the manufacture of galaxies. Had the variation been smaller the galaxies could not have formed. The larger cool spots evolved to become voids free of stars and galaxies. COBE had found the fossils Gamow was looking for.

George Smoot, the team leader from Lawrence Berkeley Laboratory, said, "It's like looking at God." Others have commented it is more like looking at a "baby picture" of the universe. [3p7] In his book, *Wrinkles in Time,* Smoot remarked, "There is no doubt that a parallel exists between the Big Bang as an event and the Christian notion of creation from nothing." Stephen Hawking described the findings as "the scientific discovery of the century, if not all time."

In recent years NASA's Wilkinson Microwave Anisotropy Probe (WMAP) launched in 2001, has provided a CBR map that was far more detailed than the COBE DMR map (Figure 3).

The hotter regions are in red, the slightly cooler regions in blue. These actually represent very tiny CBR variations with fluctuations on the order of a millionth of a decree K and represent variations in the density of the cosmos during the early years of the universe.

Current Version of the Big Bang

The current concept of the Big Bang in terms of how the various forces and particles outlined above, came into being, is summarized in Figure 4.

The following is a description of some of the aspects of the Big Bang that have the most relevance to religious and spiritual issues. For a much more detailed account

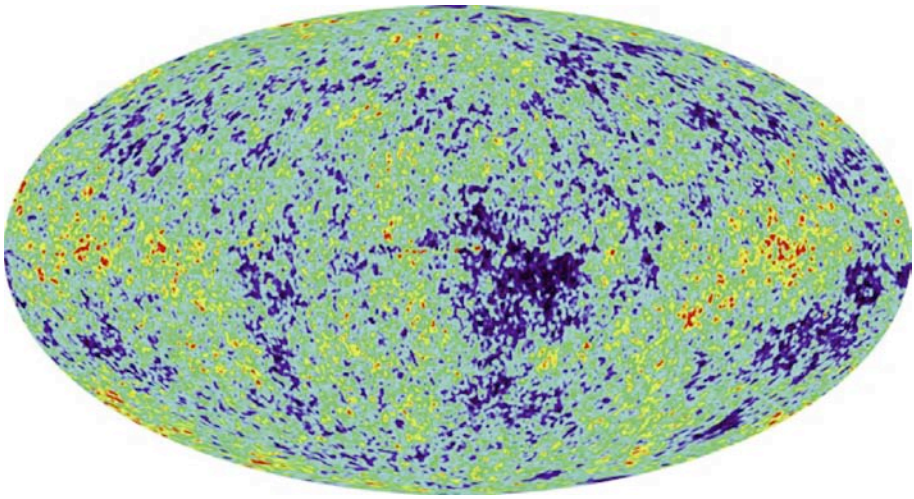

Figure 3. Map of the cosmic background radiation produced by the NASA Wilkinson Microwave Anisotropy Probe and the NASA and the WMAP Science Team. [6]

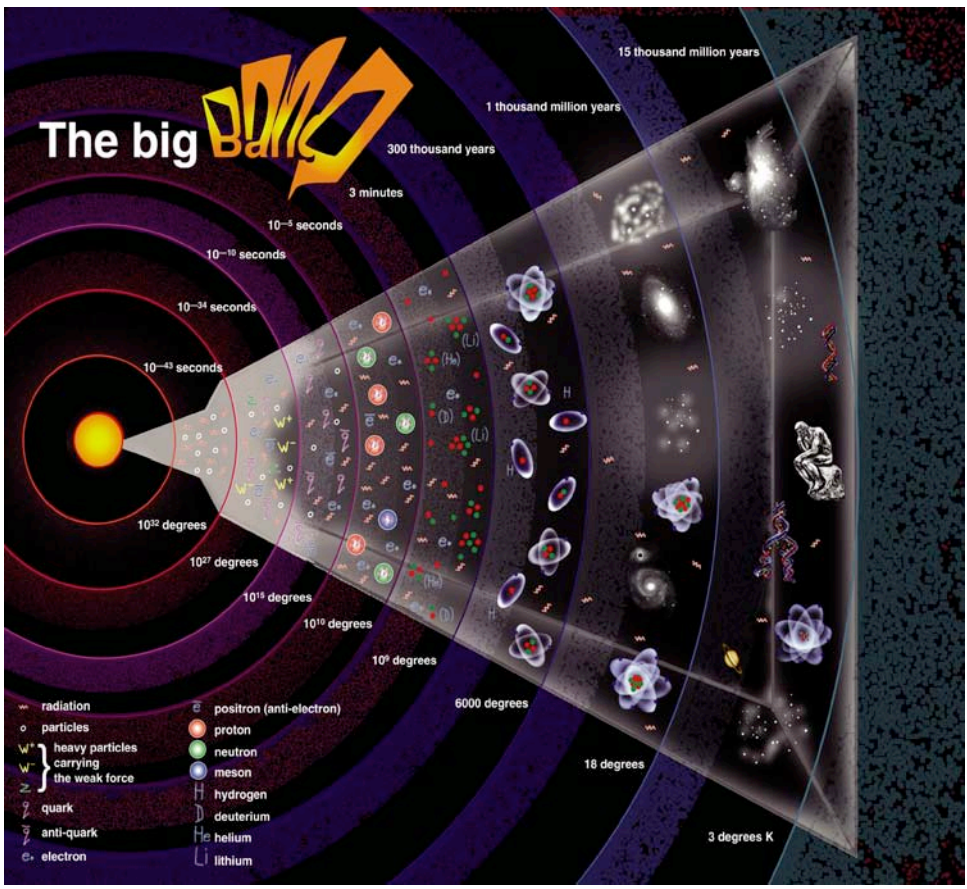

Figure 4. Diagrammatic representation of the Big Bang and the evolution of the universe. [7]

the reader is referred to the book *Origins,* by Neil de Grasse Tyson and Donald Goldsmith, [1] and *Parallel Worlds,* by Michio Kaku. [3]

One of the most critical questions is *what came before the Big Bang?* Did time start or has time always existed? The most popular version is that the universe began as a random fluctuation due to quantum instability in space that resulted in a single bubble that was the size of the Planck length, or 10^{-33} centimeters. This was hyperinflated 10^{50}-fold by space vacuum to fill the universe and started the universe on the path to the formation of matter based on Einstein's equation $E = mc^2$.

At the instant of the Big Bang, all four forces were unified into a single, coherent "superforce." All four forces had the same strength and were in perfect supersymmetry. Very quickly this symmetry began to break; the common force cracked and gave rise to the four currently known forces, with gravity being the first to split off.

The initial *inflation* stage of the Big Bang occupies such a short period of time and such a concentrated form of energy and particles, that it is difficult to conceive. Here Einstein's world of relativity and the micro-world of quantum mechanics are indistinguishable. The time of what is called the period of inflation was from 10^{-43} to 10^{-35} seconds, an extraordinarily short period of time. The energy for the inflation was produced in part by the splitting apart of the strong and weak force. The weight of the packed energy and matter was 100 trillion trillion trillion pounds. This degree of compactness is possible because the space filling atoms with orbiting electrons do not exist. During this period only energy and free particles existed. This universe was tiny (one inch in diameter) and extremely hot, 10^{32} °K.

The radiation was so energetic that the wavelength for the photon was in the cosmic ray range. The energy of the photons was sufficient for them to convert their energy into matter and anti-matter. This provides another place where everything could have gone wrong. When matter and anti-matter clashed, photons were re-formed. However, for every billion anti-matter particles formed, a billion and one matter particles were formed. Without this tiny difference all the matter of the universe, and eventually all life, would have never formed. [1p26]

> **Cosmic Weirdness #1: In the earliest stages of the universe, the energy of the photons was sufficient for them to convert their energy into matter and anti-matter. When that matter and anti-matter clashed, photons were re-formed. For every billion anti-matter particles formed a billion and one matter particles were formed. Without this tiny difference all the matter of the universe, and eventually all life, would have never formed.**

The *first second* saw the formation of quarks, anti-quarks, leptons, electrons, protons, neutrons, and neutrinos. The temperature dropped to 10^9 °K.

The first three minutes saw the beginnings of the nuclei of the lightest and simplest elemental nuclei for hydrogen (one proton), deuterium (one proton, one

neutron), and helium (two protons and two neutrons). If the universe had not cooled and expanded rapidly, all the hydrogen would have condensed into heavier nuclei. Then no water and no life would have been possible. These nuclei still had no electrons. At this time the universe was 330 trillion miles in diameter.

During the *first 300 thousand* years the universe continued to rapidly expand and cool, but it still was very hot. Electrons now orbited around the nuclei, forming the first common simple elements, hydrogen and helium. The capture of the electrons by atomic nuclei now allowed light to escape from the universe. The universe was 500 thousand trillion miles across.

After *100 million years,* with continued cooling and before the formation of stars, there was no light in the universe. Things were very dark. The universe was 10 million trillion miles across.

After *one billion years* stars had formed and their light, produced by thermonuclear fusion, brought light to the universe. They clustered to form galaxies and clusters of galaxies. The suns that were 10 times the mass of our sun had sufficient mass and pressure to fuse nuclei of lighter elements to form heavier elements. Some of the most important of these for life are carbon, oxygen, sodium, and calcium. When these stars died and exploded they dispersed these elements throughout the universe. The universe was now 60 million trillion miles across.

Now, *13.7 billion years later,* there are billions of galaxies each with billions of stars, many with planets. The current universe is 590 million trillion miles across. Our solar system formed about 8 billion years ago.

Inflation and the Speed of Light

In 1979 Alan Gurth at the Stanford Linear Accelerator Center in California proposed that in that time period from 10^{-43} to 10^{-35} seconds after the start of the Big Bang, the universe expanded at an incredible rate by a factor of 10^{50}. This super-rapid expansion was consistent with a flat universe model, since it flattened matter out like it was spread onto the surface of a huge balloon. Inserting this period of hyperinflation solved many thorny problems in cosmology. However, one problem it seemed to create was that this rate of expansion was considerably faster than the speed of light. How is that possible? Nothing is supposed to travel faster than the speed of light. Yet it can. The reason is as slippery as the famous comment, "It depends what your definition of is, is." Einstein's speed limit applies only to objects moving within space and not to the expansion of space itself.

Cosmic Weirdness #2: In the first fractions of a second of the Big Bang, the rate of expansion of the universe considerably exceeded the speed of light. Nothing is supposed to travel faster than the speed of light. However, this rule of Einstein's applies only to objects moving within space, not to space itself. Space itself can expand faster than the speed of light.

The Rate of Expansion of the Universe is Accelerating

At the time that Einstein was producing his famous equations, there was no evidence from astronomers that the universe was either expanding or contracting. To ensure that his equations did not upset this cosmological stability, Einstein inserted a "cosmological constant." When Alexander Friedman proposed that the universe was unstable and Hubble proved it was expanding, Einstein pronounced his cosmological constant as his greatest blunder. Equations now had no need for a cosmological constant. No need, that is, until 1998. That is when two independent groups of astronomers published evidence that not only is the universe expanding, it is expanding at a constantly accelerating rate. Now a cosmological constant had to be re-inserted into the equations to ensure the universe continued to expand at an ever-increasing rate. Einstein was right after all.

> **Cosmic Weirdness #3: The universe is expanding at an accelerating rate. It is not a balanced static universe. It is not even a balanced exploding universe. It is an exploding, exploding universe where the rate of expansion keeps accelerating.**

Dark Matter and Dark Energy

Of all of the incredible new knowledge of the cosmos one of the most incredible is two things we do not understand—dark matter and dark energy? As shown in Figure 5, the known normal matter consisting of the protons and neutrons of all the atoms of the universe makes up only 4 percent of the total universe.

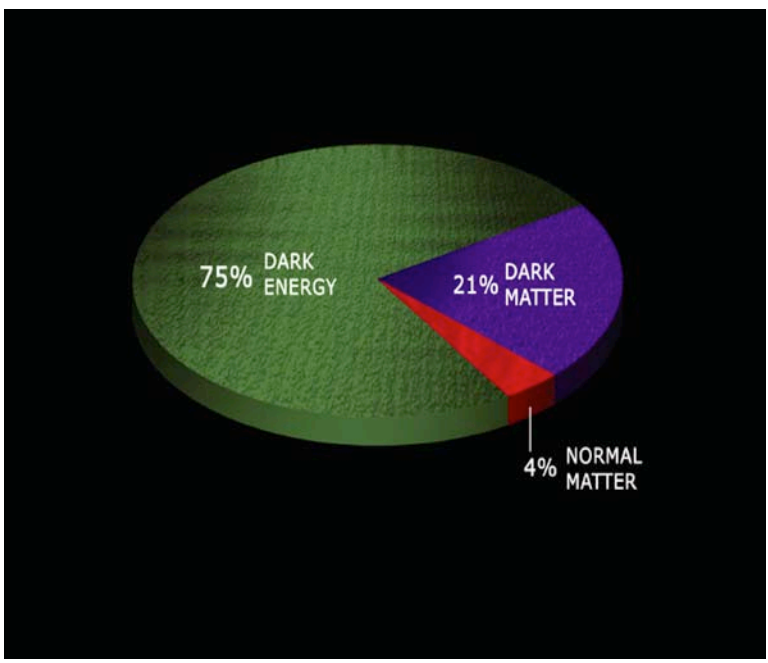

Figure 5. The proportion of dark energy and dark matter in the universe [8].

Dark matter makes up 21 percent, and dark energy the remaining 75 percent. Since the make-up of these dark things is a mystery, the nature of a whopping 96 percent of the universe is unknown.

In 1933, in the process of measuring the velocities of galaxies whose gravity interacted with nearby galaxies, astronomers identified what was termed *missing matter.* Several years later Fritz Zwicky, an astrophysicist at the California Institute of Technology, was studying a cluster of galaxies known as the *Coma Berenices cluster.* He found that the velocity of some of the galaxies in this cluster was unexpectedly high. In fact the speeds were so high that the cluster of galaxies should have flown apart billions of years ago, but they did not. The cluster did not contain enough visible matter to prevent this from happening. Again, there had to be some missing matter. As shown in Figure 5, dark matter constitutes 21 percent of the mass of the universe. On average, across the universe it constitutes about six times the amount of visible matter. This has been called *dark matter* because the source of it is invisible. Dark matter and visible matter tend to occupy the same parts of the universe as though they had some type of interdependence. In the same issue of *Science* mentioned in the previous chapter in relation the quantum weirdness, the identity of dark matter was first on the list of important questions yet to be answered in science.

As with other aspects of the universe, the amount of dark matter was "just right." If there was too little dark matter, too much of the hydrogen would have been fused into helium. [1p72] If there was too much dark matter, the universe would be collapsing instead of expanding.

In the mid 1990s scientists realized that even after dark matter was included in the calculations, the total density of matter in the universe only came to one quarter of the critical density calculated by Einstein. After the 1998 studies, showing that the rate of expansion of the universe was accelerating, the question was raised, *What is causing this accelerated expansion?* The relevant equations constantly pointed to *dark energy*. Einstein showed that energy has mass and as shown in Figure 5, dark energy constitutes 71 percent of the total mass of the universe. Dark energy drives the expansion of the universe. As it expands more dark energy is generated and the rate of expansion increases still further. Dark energy arises from empty space, or to put it in the inverse, empty space contains huge amounts of dark energy.

Cosmic Weirdness #4: Only four percent of the universe is composed of visible matter, 21 percent is dark matter, 75 percent is dark energy. The exact nature of 96 percent of the universe is unknown to us.

It has been proposed that empty space in fact buzzes with "virtual particles," which wink into and out of existence instantaneously. Quantum physicists refer to this as *quantum fluctuations in a vacuum.* When the amount of energy residing in a cubic centimeter of space is calculated, the result boggles the imagination; it's 10^{120}

times greater than the energy of supernovae explosions and the total CBR. It comes as no surprise that there is considerable controversy over the correctness of this conclusion. Tyson and Goldsmith said of this figure, "Some embrace it; some accept it only reluctantly; some dance around it; and some despise it." [1p99-102]

Cosmic Weirdness #5: The amount of energy in a cubic centimeter of free empty space has been calculated to be 10^{120} times that of a supernova explosion and the total CBR.

Different values of the cosmological constant would produce many different amounts of dark matter over dark energy. Some would be consistent with life, but many would not. Some cosmologists have suggested our universe is part of a much larger "multiverse" in which many different universes with different cosmological constants exist. Since this concept is more relevant to Chapter 23, The Anthropic Principle, it will be discussed further there.

Black Holes

In 1915 Einstein published his theory of general relativity describing how space and matter interact. A short time later Karl Schwarzschild, a German physicist, showed that objects with sufficiently strong gravity would create a situation in which nothing, including light, could escape. This was called a *singularity.* In 1967 these objects were termed *black holes* by John Wheeler. The existence of black holes was soon proven. There is a black hole in the center of every quasar (quasistellar radio sources) and at the center of most giant galaxies. Astronomers estimate there are 300 million black holes in the universe.

Origin of the Solar System and the Earth

There have been many theories of the origin of the solar system, such as beginning as a rotating gaseous nebula that condensed in places to form the planets (nebular hypothesis); a collision of the sun with a passing star (catastrophe hypothesis); condensation of stellar dust; and others. Mathematical analyses have ruled out these models.

The currently favored model is a *solar nebula cold accretionary model*, with the formation of the earth 4.6 billion years ago. Harold Urey proposed that the terrestrial planets were formed at a relatively low temperature of 1,200°C. While this may seem hot to us, it is cold compared to the temperature of the sun. Turbulence and eddies in the solar nebula led to the formation of primitive planets. At this temperature the light elements such as hydrogen and helium were driven off, while the heavier elements were retained. The heaviest of these, such as iron and nickel, were retained and form the molten core of the earth. The less heavy elements, such as calcium, sodium, and potassium, formed the mantle and crust. The larger more distant planets such as Jupiter were composed of frozen methane, water and ammonia.

Is the Big Bang Relevant to Theology and Human Spirituality?

The Big Bang theory, positing the creation of the universe from nothing, has been a boon to theists. The relevance of the Big Bang and other cosmological weirdness to religious, theological and spiritual issues will be discussed in Chapter 24.

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Chapter 22

String Theory: A Cosmic Symphony

It is well known that for the last 30 years of his life Albert Einstein attempted to find a grand unified field theory that would unite the macro-world of relativity with the micro-world of quantum theory. He failed. As mentioned in the previous chapter, part of this failure was that he was not aware of two subatomic range forces in the universe—the strong and the weak forces. In addition, the subatomic particle soup was still only a half-cooked meal.

Every advance that has been made in the field of physics and atomic physics has come from identifying smaller and smaller units of energy and mass. For energy it was the discovery by Planck that energy comes in quanta, defined by multiplying Planck's constant, 6.626×10^{-34} Joule-seconds, by frequency. For mass, it was the identification of the subatomic particles: electrons, protons, neutrons, and neutrinos. This was followed by the identification of quarks as subparts of protons and neutrons. It should be no surprise then, that the next advance in cosmology has proposed something still smaller—strings.

Strings

Instead of a small particle, superstring theory, or more simply *string theory,* proposes an extraordinarily small vibrating loop like a tiny rubber band. The beauty of a loop instead of a still smaller particle is that variations in the length and rate of vibration of the loop can provide a basis for the formation of all of the forces and particles listed in the previous chapter. The amount of energy in a given string is reflected in its size and rate of oscillation. In our world the best analogy is a violin string. Differences in length produced by our fingers, and variation in oscillation produced by the bow, produce a rich range of sound. With string theory a single fundamental resonant pattern of vibration forms the basis of all the fundamental forces and particles.[1 p15] A diagrammatic representation of these strings is shown in Figure 1.

Since it is capable of uniting the world of relativity and the world of the quantum and since there is no need for a still deeper explanation, string theory and its latest incarnation, M theory, have been termed a *Theory of Everything,* or TOE. While the mathematics of these theories is incredibly complex, the concept itself and its cosmological implications are understandable to all. This understanding has been

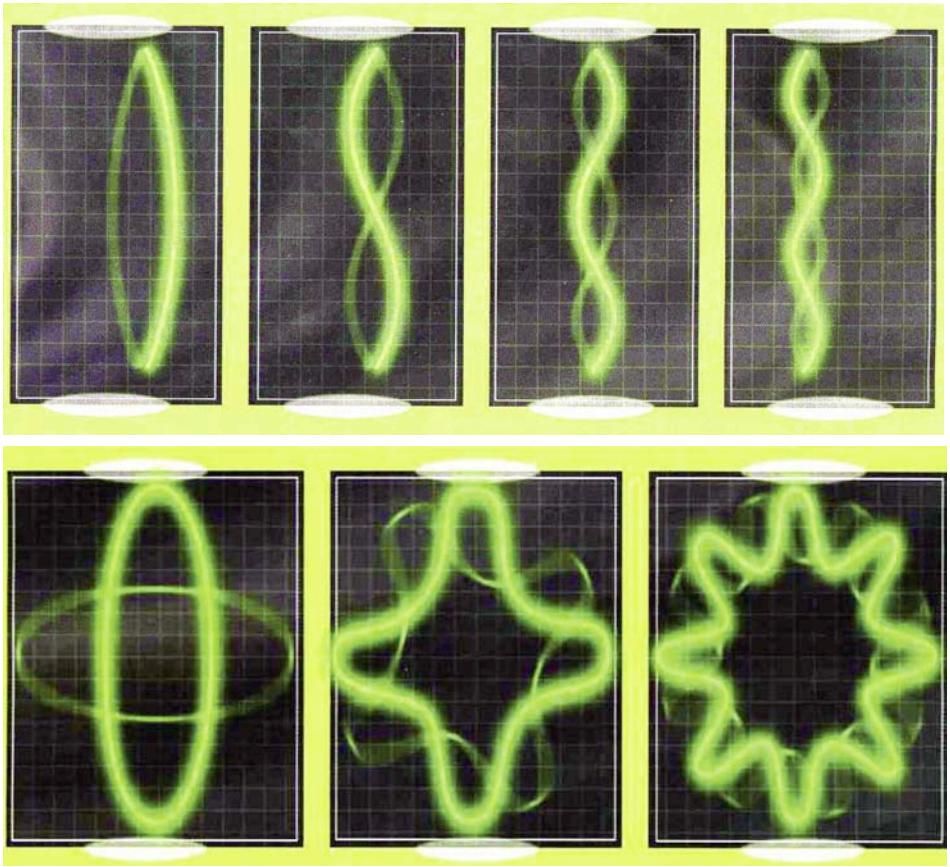

Figure 1. Diagram of different strings of string theory. From M. Kaku Testing String Theory. Discover. *26:30-37, 2005. By permission.*

made possible by the popular writing of some of the scientists involved. For readers who wish more details than the brief summary being presented here, I recommend Brian Greene's *The Elegant Universe* [1] and *Fabric of the Cosmos,* [2] and Michio Kaku's *Parallel Worlds.* [3]

String Theory

The problem with the standard model was that the force of gravity was not explained by the otherwise very precise quantum theories that unified the three other fundamental, non-gravity forces. At the submicroscopic scale of Planck's length (10^{-33}cm), the normally quiet and well-behaved space-time fabric became a chaotic sea of quantum jitters. A TOE. was needed that unified everything.

The first beginnings of string theory go back to 1968 when Gabriele Veneziano at CERN noted that an obscure mathematical formula proposed by Leonhard Euler, known as the *Euler beta-function,* seemed to explain many aspects of strongly interacting particles. In 1970 a group of three physicists, Yoichiro Nambu, Holger Nielsen, and Leonard Susskind, showed that if elementary particles were modeled as tiny vibrating strings their interactions were predicted by Euler's beta-function.

However, at that time this theory seemed to conflict with experimental high-energy physics relating to the strong force.

This apparent conflict appeared to be resolved in 1974 when John Schwarz and Joël Scherk showed that string theory could explain both the strong force and the force of gravity. Gravity represented the lowest vibration of the string with zero mass. Despite this, conflicts between string theory and quantum mechanics persisted until the 1984 landmark paper by Michael Green and John Schwarz showed that string theory could encompass all of the four forces, including gravity, and all of the fundamental particles. Thus, string theory is quantum theory plus gravity. This launched a period known as the *first superstring revolution.* Strings were the size of Planck's length—a millionth of a billionth of a billionth of a billionth of a centimeter. A persisting problem was that the mathematics was so complex that only approximations of the theory could be solved, and these failed to answer all of the questions involved.

An even greater problem was that over the years a number of different string theories had evolved based on adding new dimensions of space. There were now nine space dimensions and one time dimension. Thus, in addition to the three dimensions of space and the fourth dimension of time that we can directly experience, there were six additional dimensions curled up into such tiny structures that they were not available to our conscious perception. Five different versions of string theory evolved, each of which seemed to work. This plethora of suitable answers is not what scientists are used to. A much more satisfactory outcome is to fight over different possible answers, then eventually come to a single answer all could agree on. The existence of five suitable answers raised the disturbing possibility that perhaps none of them were correct. String theory seemed to be on the ropes, or more literally, on the strings.

M-Theory

The "second superstring revolution" was launched by a lecture by Edward Witten at a 1995 superstring conference. He had discovered a hidden unity that tied all five string theories together. Rather than being distinct, the five theories were actually five different ways of mathematically analyzing a single grand theory. [2p379] The unified theory had 11 dimensions, 10 for space and one for time. The new tenth space dimension was much smaller than the others but this allowed a unification of all five string theories. The new theory was called M-theory. Apparently, no one knows for sure what the M stands for: Membrane? Master? Majestic? Mother? Magic? Mystery? Matrix?—or all of the above.

The beauty of string theory is that the different properties of all 19 of the fundamental particles, their mass and force charges, are determined by the precise resonant pattern of vibration of different size strings. The greater the amplitude and the shorter the wavelength, the greater the energy of the string. Since Einstein showed the equivalence of energy and mass, the greater the energy, the greater the mass. Thus, heavy particles are composed of strings that vibrate more energetically. The different forces are determined by the manner in which the strings vibrate. All strings are the

same and they represent the ultimate fundamental stuff of the universe. Current theory suggests everything is composed of vibrating strings and there is nothing below a string. The string truly provides us with a cosmic symphony. [1p146]

String theory and M-theory propose that the ultimate building blocks of the universe consist of tiny (10^{-33} centimeter) vibrating strings. Different lengths and vibration frequencies of these strings produce all four fundamental forces and all 19 fundamental particles. Since the force of gravity was now included in a unified theory, M-theory has been called the theory of everything, or T.O.E.

Multiple Universes—Darwinian Selection of Universes

One of the thorny problems with the inflation part of the Big Bang was, "What put the brakes on the process?" "What stopped the inflation at just the right time?" This had to have occurred just when it did or the current universe could not have formed. The physicist Andrei Linde proposed a novel solution. He suggested that the brakes were applied randomly but that the quantum bubble in vacuum space that gave rise to our universe actually occurred millions of times, each with a different braking time. When omega was too large, the new universe immediately self-destructed. When omega was too small, the inflation went on indefinitely. By a form of *Darwinian selection of universes,* when everything was just right and the timing was perfect, it gave rise to the universe as we know it. In this model Big Bangs are happening all the time and new universes are budding or sprouting off to form a giant "multiverse." As shown in the next chapter, this concept of multiple universes also provides a possible answer to the anthropic principle.

Branes, Parallel Universes, and Cyclic Cosmology

Quantum theory states that there is a finite possibility that the seemingly impossible can happen. Thus, if one universe can be produced by a quantum instability in the vacuum of space, it is extremely probable that this will happen more than once, perhaps millions or billions of times, giving rise to many parallel universes. This concept has now been taken as a given by most cosmologists.

This concept is also consistent with M-theory which predicts multi-dimensional objects called *membranes,* or *branes* for short. This is such an integral part of M-theory that most physicists assume M-theory was so named for membranes it predicted. These branes can have three or more, but 10 or fewer spatial dimensions. This led to the possibility that our flat universe was a giant brane, and that the parallel universes are parallel three-dimensional branes.

As an extension of this, Paul Steinhardt and Neil Turok of Cambridge University proposed that we are living in the three-dimensional brane that collides every few trillion years with a parallel brane and that this collision is the cause of the Big Bang. This collision produces two new parallel branes that undergo accelerated expansion until they are largely depleted of matter. Then a new collision repeats the process

resulting in a cyclic cosmology.[2] They referred to this as an *ekpyrotic model* of the cosmos. *Ekpyrosis* is Greek for conflagration.

A Universe from Nothing

The formation of our universe from so little and the notion of a multiverse with budding universes might seem to violate the laws of the conservation of matter and energy. However, as pointed out by Kaku,[3p94]

> The total matter/energy content of a universe may actually be very small. The matter content of the universe, including all the stars, planets, and galaxies, is huge and positive. However, the energy stored within gravity may be negative. If you add the positive energy due to matter to the negative energy due to gravity, the sum may be close to zero! In some sense, such universes are free. They can spring out of the vacuum almost effortlessly.
>
> In fact, to create a universe like ours may require a ridiculously small net amount of matter, perhaps as little as an ounce.

When the galaxies are compared, their total spin cancels out to zero and the positive and negative charges in the universe cancel out to 1 part in 10^{21}.[3p95] Thus, in addition to matter and energy, other aspects of our universe also tend to cancel each other out.

> **The total amount of matter + energy in the universe may be almost zero when the negative mass of the energy stored within gravity is summed with the positive mass of the universe. In this sense universes can spring out of the vacuum almost effortlessly.**

Implications of String Theory for Theology and Spirituality

As with the Big Bang, there are some profound implications of string theory and multiple universes for theology and the existence of God. These theological implications will be discussed in the final chapter of Part III on cosmology.

> **The universe was formed from a tiny bubble randomly produced out of the quantum jitters of empty space. The space vacuum produced the hyperinflation initiating the Big Bang. If this could occur once, it could occur many times, suggesting there may be billions or trillions of parallel universes.**

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Chapter 23

The Anthropic Principle

The *Anthropic Principle* states that the laws of nature are arranged so that life and consciousness are possible. Brandon Carter[1] first proposed this in 1973 during a symposium on *Confrontation of Cosmological Theories with Observational Data.* The symposium was celebrating the 500th birthday of Copernicus. The *Copernican Principle* claimed the opposite, that man does not occupy a privileged position in the universe. Carter's paper was entitled, "Large number of Coincidences and the Anthropic Principle in Cosmology." He stated that, "Although our situation is not necessarily central, it is inevitably privileged to some extent." The "large number of coincidences" refers to the extraordinary degree of fine-tuning of many of the constants of the universe so they are "just right" for the universe and life to develop — the so-called "Goldilocks" effect. This aspect of the Anthropic Principle has been widely used by Intelligent Designers and theologians in general to "prove that God exists."

In their extensive opus on the subject entitled *The Anthropic Cosmological Principle,* John Barrow and Frank Tipler[2] defined four flavors of the Anthropic Principle.

1. Weak Anthropic Principle (WAP).

The WAP is defined as: [2p16]

> The observed values of all physical and cosmological quantities are not equally probable but they take on values restricted by the requirement that there exist sites where carbon-based life can evolve and by the requirement that the Universe be old enough for it to have already done so.

A simpler, easier-to-understand, and more-modern version is:

> Among all possible multiple universes there is at least one that allows the evolution of intelligent life.

2. Strong Anthropic Principle (SAP)

The SAP is defined as: [2 p21]

> The universe must have those properties which allow life to develop within it at some stage in its history.

Or:

> The elementary particles and fundamental forces are uniquely those that allow the evolution of intelligent life.

The SAP is considered a strong version because it carries the implication that the constants and laws of nature *must* be such that life can exist. The SAP leads to a number of additional implications:

> **A.** There exists one possible universe "designed" with the goal of generating and sustaining "observers."

This is the teleological form of the Anthropic Principle and suggests "design" in its most unambiguous form. It is naturally favored by theologians but some astronomers such as Fred Hoyle ascribe to it as well. Hoyle stated: [3]

> I do not believe that any scientist who examined the evidence would fail to draw the inference that the laws of nuclear physics have been deliberately designed.

> **B.** An ensemble of other different universes is necessary for the existence of our Universe.

This B version receives support from the many-worlds interpretation of quantum mechanics. The third flavor of the Anthropic Principle was proposed by the physicist John Wheeler. [4,5]

3. Participatory Anthropic Principle (PAP)

The PAP states:

> Observers are necessary to bring the Universe into being.

PAP is a massive extension of one of the aspects of the Copenhagen Interpretation of quantum theory that an observer collapses the wave function of a particle or object and brings it into reality. This suggests a feedback loop between man, the observer, and the universe, and proposes the production of reality by observing works backward to the beginning of the universe.

4. Final Anthropic Principle.
This states that:

> Intelligent information processing must come into existence in the Universe, and, once it comes into existence, it will never die out.

What are the Constants that Must be Exactly as They are for Life to Exist?

There are many sources for the list of physical and cosmological constants that had to be just right for life to have occurred in our universe and in our solar system. I will start with those listed by Sir Martin Rees, the Astronomer Royal at Cambridge University in England. In his book *Just Six Numbers,* [6] he describes six numbers that seem especially significant.

N measures *the ratio of the strength of the electrical forces that hold atoms together, divided by the force of gravity between them.* Because the force of gravity is so small the number is huge—1,000,000,000,000,000,000,000,000,000,000,000,000,000, or $1x10^{36}$. The very high value is a reflection of the weakness of the force of gravity. If the force of gravity was weaker, the stars would not have formed and the universe would be dark and lifeless. If gravity was stronger, the stars would heat up too fast and burn up too quickly for life to form.

ε (epsilon) is a measure of the *strong nuclear force* that defines how strongly atomic nuclei bind together. It has a value of .007. This means that hydrogen converts .007 of its mass into energy when it fuses into helium. Epsilon also controls the fusion of hydrogen atoms into heaver elements, including carbon and oxygen. If it were .006, protons and neutrons would not bind together. Our entire universe would have dissolved into hydrogen with no neutrons. If epsilon were .008, the fusion would have been so rapid that no hydrogen would have survived the Big Bang and the stars would burn their nuclear fuel too quickly for life to evolve.

Ω (omega) is the *cosmic density factor* and measures the amount of matter in the universe, including all the galaxies, diffuse gas, and dark matter. It is a *ratio of the importance of gravity pulling the universe together, and the expansion energy pushing the universe apart.* The current assessed value of omega is 0.3. For it to currently be anywhere between .1 and 10, the value of omega had to be accurate to an exact value of 1.00000000000000, one second after the Big Bang. If too small then the universe would have expanded and cooled too fast. If too large, the universe would have collapsed before life could start. Rees states,

> At one second after the big bang, omega cannot have differed from unity by more than one part in a million billion (10^{15}) in order that the universe should now, after 10 billion years, be still expanding and with a value of omega that has certainly not departed wildly from unity. [6]

Stephen Hawking weighed in as follows:

> If the rate of expansion one second after the big bang had been smaller by even one part in a hundred thousand million, [the universe] would have collapsed before it reached its present size.…The odds against a universe like ours emerging out of something like the big bang are enormous. I think there are clearly religious implications. [17]

λ (lambda) is the *cosmological constant* which determines the rate of expansion of the universe. If much larger, antigravity forces would be created and blow the universe apart. If much smaller, the universe would have re-contracted into a singularity, giving too little time for life to develop. Alan Gurth [7] suggested that to prevent these problems λ had to be just right to one part in 10^{55} parts. This is probably an exaggeration. His paper was written in 1981 when the cosmological constant was thought to be zero, consistent with a universe that was expanding at a constant rate. Recent studies have shown that lambda is slightly greater than zero, yet here we are.

Q is the *ratio of two fundamental energies* and has a value of 1/100,000 or 10^{-5}. If it were smaller, the universe would be inert, smooth, and structureless, and the stars and galaxies would not have formed. If it were larger, the universe would be violent and dominated by black holes.

D is the *number of spatial dimensions in the world.* This refers to macro dimensions rather than the ultra tiny fourth to tenth spatial dimensions of string theory. Rees referred to these as the three dimensions of our visual experience. One or two dimensions would obviously not have worked. We would live in the world of *Flatland.* Four dimensions and the planetary and atomic orbits would be unstable.

Rees picked these constants because they are fundamentally independent in that one cannot be computed from any of the others. The following are two additional important examples from the literature.

Ratio of protons to anti-protons. This was mentioned previously but will be repeated here. Immediately after the Big Bang the energy of photons was converted to protons and anti-protons. When these interact they destroy each other with the release of energy. The current universe formed because the ratio of protons to anti-protons was 1,000,000,001/1,000,000,000. Without this tiny difference, all the matter of the universe would have never formed. [8p26]

α (alpha) or the *fine structure constant* = $e^2/2e_o hc$. It quantifies the relativistic (c) and quantum (h) qualities of electromagnetic (e) interactions involving charged particles in empty space (e_o). It is equal to 1/137.035599976, or approximately 1/137. This value accounts for why 137 has legendary status among physicists. There

is some evidence that this value has changed slightly over the time of the universe, but if it had a significantly different value, matter and energy would interact in bizarre ways such that the distinction between the two could melt away. [9]

A More-Complete List of Anthropic Constants

Hugh Ross has published a longer list of anthropic constants [10p121] Those that are relevant for the whole universe are listed in Table 1 along with the consequences of higher or lower numbers. There is some overlap with the constants already discussed.

Table 1. Additional Anthropic Constants.

Constant	Consequence of larger#	Consequence of smaller#
Gravitational force	Stars burn too fast	No heavy elements
Strong nuclear force	No hydrogen	Only hydrogen
Weak nuclear force	Too many heavy elements	Too few heavy elements
Electromagnetic force	No sharing of electron orbits	Electrons fly off elements
Age of universe	No life possible	No earth-type suns
Expansion rate of universe	Universe would not form	Universe would collapse
Mass of universe	No galaxy formation	No heavy elements
Ratio electron/proton mass	Elements would not form	Elements would not form
Ratio EM force/gravity	Short life span of stars	No heavy elements
Ratio protons/anti-protons	No mass in the universe	No mass in the universe
Ratio protons/baryons	No galaxies would form	No stars would form
Ratio protons/electrons	No galaxy formation	No galaxy formation
Stability of the proton	Excess radiation lethal to life	Too little matter
Uniformity of universe	Too many black holes	No galaxies would form
Velocity of light	Stars too luminous	Stars too dim
^{4}He nuclear energy level	Too little oxygen and carbon	Too little oxygen and carbon
^{8}Be nuclear energy level	Excess nuclear fusion	No heavy elements
^{12}C nuclear energy level	Incompatible with C life	Incompatible with C life
^{16}O nuclear energy level	To little conversion of C to O	Excess conversion of C to O
Distance between stars	No heavy elements	Destabilize planet orbits
Rate of star luminosity	Excess greenhouse effect	Excess freezing of water
Distance between galaxies	Inadequate star formation	Disturb sun's orbit
Mass of neutrino	Stars would not form	Galaxies too close

Ross [10p129] also provided a list of constants that had to be just right for life in our solar system. These included:

The position of the solar system in our galaxy, the Milky Way. Our solar system is currently two-thirds of the way from the center of the galaxy, where a black hole lurks. If the solar system were too close to this black hole, the radiation it emits would be lethal to life. If the solar system were too far from the center, there would not be enough heavy elements, like iron, necessary for life.

The size of the earth. If it were smaller its gravity would have been so weak that the oxygen would not stay in the atmosphere. If it were larger many of the toxic primordial gases would have been retained. While it is likely that life could still have evolved, it would be dramatically different than life as we know it.

The size of Jupiter. The current size of Jupiter cleaned the solar system of asteroids that would have destroyed the earth. Jupiter is our asteroid protector. If Jupiter were

much smaller it would not have been our protector.

Other figures include the age, color, and size of our sun; the distance of the earth from the sun; the size of the moon, and the tilt, rotation period, force of gravity, magnetic field, thickness of the crust, oxygen-to-nitrogen ratio, level of carbon dioxide, oxygen, and ozone level of the earth. Even these represent a partial list, but they clearly make the point that many constants of the universe, our galaxy, and our solar system had to be just right for life to occur. There are several interpretations of the Anthropic Principle.

- It is proof of the existence of God since only a divine presence could fine tune the universe with such accuracy.
- It is a tautological illusion.
- There are actually only a few true anthropic constants.
- It was a lucky accident.
- There are millions of universes and it was inevitable that in at least one the conditions would be suitable for life. If it were not, we would not be here to ask the question of "why?"

These are all discussed in the next chapter. For now, what do different scientists think of the Anthropic Principle?

Comments by Various Scientists

The Anthropic Principle elicits strong opinions from different people. Theists love it because it suggests intelligent design and thus "proves" that God exists. This position has been strongly voiced by Hugh Ross, a Christian astronomer who, while he believes in evolution and an old earth,[12] still believes in the literal truth of the Bible. He has written two books on the Anthropic Principle: *The Fingerprint of God*[10] and *The Creator and the Cosmos.*[11] The subtitles of these books, *Recent Scientific Discoveries Reveal the Unmistakable Identity of the Creator* and *How the Latest Scientific Discoveries Reveal God,* clearly indicate his view that the Anthropic Principle proves the existence of God.

In the book called *A Case Against Accident and Self-Organization,* Dean Overman, a lawyer and writer of a range of other books, proposes that the Anthropic Principle and other observations in nature argue against the proposition that the universe and the life in it could have developed from chance events. While he does not specifically mention God, this is an Intelligent Design-type of argument. It is clear that the Intelligent Design movement is meant to include cosmology as well as evolution. Other books that propose that the Anthropic Principle proves God exists include those by Nathan Aviezer,[13] Fred Heeren,[14] Patrick Glynn,[15] and others. John Polkinghorne, a particle physicist-turned-clergyman, can gave both a scientist's and a theist's opinion. He stated:[16]

> The Weak Anthropic Principle amounts to little more than tautology.

> "We're here and so things are the way that makes that possible." It fails adequately to encapsulate the remarkable degree of "fine-tuning" involved in spelling out the conditions that have permitted our evolution. Only a tiny fraction of conceivable universes could have been the homes of conscious beings.

He fundamentally believes that the world is fine-tuned because it is the creation of a Creator who wills that it be so.

Some physicists hate the Anthropic Principle because it suggests Intelligent Design and has been used to "prove" that God exists. Other physicists have suggested that we may have to accept the fact that the existence of life was built into the laws of physics from the beginning. Isaac Newton believed that the elegance of the laws he formulated pointed to the existence of God. Vera Kristiakowsky, an MIT physicist says, "The exquisite order displayed by our scientific understanding of the physical world calls for the divine." Physicist Freemon Dyson said "It's as if the universe knew we were coming." Stephen Hawking[17] said,

> It would be very difficult to explain why the universe should have begun in just this way, except as the act of a God who intended to create beings like us.

By contrast, Steven Weinberg was not convinced the anthropic principle meant anything. He stated:

> It is almost irresistible for humans to believe that we have some special relation to the universe, that human life is not just a more-or-less farcical outcome of a chain of accidents reaching back to the first three minutes, but that we were somehow built in from the beginning.

He concluded that the strong Anthropic Principle was "little more than mystical mumbo jumbo."

Strong Selective Effect

Whichever view is correct, it is clear that a strong *selection effect* is built into the Anthropic Principle. Thus, since humans represent "life and consciousness," the Anthropic Principle would not exist if the constants of the universe did not allow us to exist. Or, to put it differently, there is no Anthropic Principle in universes that have no life capable of thought and consciousness. If there were a trillion parallel universes it would be a virtual certainty that one of them would have the "just right" set of constants. The anthropic principle would be easily explained on that basis.

Is Life in the Universe Rare?

In their book, *Rare Planet,* Peter Ward and Donald Brownlee[18] expand even

further the list of constants and conditions that had to be "just right" and in the Goldilocks zone for life to occur. On this basis they argue life is probably very rare in the universe. By contrast, as noted previously, based on the fact that life on earth evolved in such a short period of time and that there are probably billions of planets in the universe, De Duve came to the opposite conclusion and proposed that life has occurred in many worlds.

Religious and Spiritual Implications of the Anthropic Principle

Before it can be concluded that the Anthropic Principle has major implications concerning the existence of God and other spiritual matters, it is necessary to examine whether the whole concept is valid or simply a tautology. Only then can the religious and spiritual implications be discussed. Both of these issues are examined in the next chapter.

The Anthropic Principle states that the laws of nature are arranged so that life and consciousness are possible. This has been proposed because there are a number of cosmological constants that had to be "just right" for life to occur. Many individuals, including some scientists, have suggested that the Anthropic Principle proves that God exists, since only a divine presence could fine-tune the universe with such accuracy. Other interpretations that do not require a divine presence are discussed in the next chapter.

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Chapter 24

Cosmology, Theology, and Spirituality

There is enough material relevant to theological, religious, and spiritual issues in the previous four chapters to fill a library of books. In fact, just in recent years over 260 books have been written on the implications of modern cosmology and physics to theology, spirituality, and the existence of God. I will attempt to keep this chapter focused on the issue of whether some aspects of cosmology prove that God exists and whether our rational and spiritual brains can come to a mutually satisfying accommodation about these issues.

For many readers, the overriding approach to this material may be one of "Don't confuse me with facts; I have already made up my mind about God." Thus, based on their upbringing and other factors in their lives, most readers will approach these issues already knowing whether they are theists, deists, agnostics, or atheists — and interpret the material based on these beliefs. This is fine. This chapter is written to those who will approach this material with the view that they might be willing to change or expand their mind in one direction or the other. If some readers find a reason to reevaluate and broaden their prior spiritual views, that is fine also. If some readers chose not to change their spiritual views, that is also fine. They may at least enjoy the debate. I will discuss the issues in the order of the previous four chapters.

1. Quantum Physics

Does the Uncertainty Principle Mean We Have Free Will?

Following the publication of Newton's opus, *Philosophiae Naturalis Principia Mathematica [Mathematical Principles of Natural Philosophy],* better known simply as *Principia,* it appeared as though the precise physical laws he described meant that everything in the universe was predictable and the the future was predetermined.

Pierre Simon Laplace, Napoleon's scientific advisor, claimed that using Newton's laws one could predict the future with the same precision that one knows the past. When he presented a copy of his masterwork, *Celestial Mechanics,* to Napoleon, the emperor was reputed to have said, "You have written this huge work on the heavens, without once mentioning God." Laplace replied, "Sire, I have no need of that hypothesis." [1p154]

Einstein, who did not believe in quantum mechanics and was also a determinist, stated:

> I am a determinist, compelled to act as if free will existed, because if I

> wish to live in civilized society I must act responsible. I know philosophically a murderer is not responsible for his crimes, but I prefer not to take tea with him. [1]

His words might have been clearer if he had said, "Even though I am a determinist and thus believe there is no free will, I am compelled to act is if free will existed." He went on to say:

> …each man explains in his own way the fact that the human will is not free.…Everything is determined…by forces over which we have no control…for the insect as well as for the star. Human beings, vegetables, or cosmic dust, we all dance to a mysterious tune, intoned in the distance by an invisible player. [1]

The concept of determinism is common in most religions where predestination is linked with the idea of a powerful all-knowing God who knows what will happen to you in the future. The uncertainty principle of quantum theory has relevance to these philosophical and theological ideas. As stated before, during the probabilistic wave function, a subatomic particle such as an electron or a photon can exist in all possible states at the same time. It can be in two or more places at once. However, once an observation is made, the wave function "collapses" and the object goes into a definite state where its position is known. On a broader philosophical scale, for those who believe in quantum theory, like Niels Bohr, reality exists only after an observation is made. By contrast, Einstein, who was less than enthusiastic about quantum theory, believed in "objective reality," where objects can exist in definite states without human intervention. The Bohr approach reminds us of the old philosophical thought, "Does a tree falling in the forest where there is no one to hear it, really make a sound?"

I always thought this type of mental mischief was silly. Of course a falling tree makes noise whether a human, or other animal, is there to hear it or not. However, with the advent of quantum theory and the precise predictions it makes, this has been elevated to what could be called, "the observer problem." If an object's wave function only collapses when it is observed, perhaps the "falling tree" question is not as silly as it seems. In fact, some of the deepest thinkers in physics have struggled with this issue. [1p165] The Nobel laureate Eugene Wigner suggested that *human consciousness determines existence.* He stated:

> It was not possible to formulate the laws of quantum mechanics in a fully consistent way, without reference to the consciousness [of the observer]…the very study of the external world led to the conclusion that the content of the consciousness is the ultimate reality.

There was also the issue of "Wigner's friend." This alludes to the thought that if

I make an observation do I need someone else to observe me to collapse my wave function? Do I then need someone to observe that person, and on and on? This could be extended to an all-encompassing cosmic consciousness. There is more than one physicist who has voiced these views. Andrei Linde, one of the founders of the concept of the inflationary universe, states:

> For me as a human being, I do not know any sense in which I could claim that the universe is here in the absence of observers.…A recording device cannot play the role of an observer, because who will read what is written on the recording device. In order for us to see that something happens, and say to one another that something happens, you need to have a recording device, and you need to have us.…In the absence of observers, our universe is dead.

Others have taken a more circuitous route to resolve the philosophical questions generated by the role of the observer in the uncertainty principle. In 1970 the German physicist Dieter Zeh outlined an approach called *decoherance.* This was formulated in relation to the famous *Schrödinger's cat* problem that has often been used to explain the uncertainty and observer principle. Here a cat is placed in a box along with a radioactive uranium source. Since the decay of uranium is a quantum event, it is totally random and cannot be predicted ahead of time. There is a 50 percent chance the decay will occur and a 50 percent chance it will not occur. The box is set up so that if a decay occurs it sets off a Geiger counter, which sets off a hammer, which breaks a vial of cyanide, which kills the cat. Before the box is opened it is impossible to tell if the cat is alive or dead—in the quantum world the cat is both alive and dead. Once the box is opened, the cat's wave function collapses and it is observed to be either alive or dead.

Zeh pointed out that for the cat to be both alive and dead, the wave function of the alive cat and of the dead cat had to be vibrating in exact synchrony, a state called *coherence.* This, however, is almost impossible, since even the presence of a few randomly vibrating air molecules in the box would destroy the coherence and thus kill the cat without any observation taking place. By this approach, consciousness and human observers are not necessary. Decoherance occurs without them and thus *reality does not need an observer.*

The problem with the decoherance explanation is that is does not answer a question that disturbed Einstein. How does nature choose the final state of the cat? To show how much brain power has been expended on this issue, physicist Hugh Everett III suggested that the multiverse could come to the rescue. In this scenario, in one parallel universe the cat is alive and in another it is dead. An advantage of this is that the wave functions never collapse, they just keep splitting into more and more parallel universes. A disadvantage is that we have to put up with millions of parallel universes just to solve the cat problem.

We eventually get around to theology and religious issues because in a final

suggested solution the observer is God. The universe exists because there is a deity to observe it. God decides whether the cat is alive or dead. God is responsible for collapsing the wave function of these objects that we see. Quentin Smith called this "the best scientific argument for God that is present in twentieth-century science. [2] Wheeler [3p583] quotes the following charming and relevant limerick:

There was a young man who said God
Must find it exceedingly odd
To think that this tree
Would continue to be
When there's no one about in the quad

Dear Sir, your astonishment's odd
I am always about in the quad
And that's why this tree
Continues to be
Since observed by, yours faithfully, God

My rational brain prefers a far simpler approach, that of Roger Penrose. As discussed previously, Penrose felt that the whole issue of the ability of subatomic particles to exist in several places at once was because the force of gravity was so weak, it could not collapse the wave function of tiny particles. By contrast the energy required to keep the larger objects in several places at once was so enormous, their wave functions immediately collapsed all by themselves. The beauty of this proposal is that the larger objects that are visible in our reality are collapsed not by an observer, man, decoherence, or God, but by gravity. Einstein was right in his belief in "objective reality" where objects can exist in definite states without human intervention. The subatomic particles that are beyond our visible observation can maintain their wave function forever until observed. In the larger reality of the real world, the wave function of objects is collapsed by gravity.

This discussion started with the issue of whether we have free will. Despite Einstein's concerns, quantum theory is correct. Determinism is not correct. The astrophysicist Kaku [1p346] put it well:

> The quantum revolution gave us an even more bizarre picture of the world. On one hand, the downfall of determinism meant that the puppets were allowed to cut their strings and read their own lines. Free will was restored, but at the price of having multiple and uncertain outcomes.

From a religious point of view, the Catholic biochemist Kenneth Miller [4] proposed that quantum indeterminacy formed the bridge between science and religion. He suggested that the element of uncertainty was deliberately introduced by God into the laws of his creation so that humans can be free to chose between good

and evil and bear responsibility for their actions.

Despite this attempt to put a positive religious spin on quantum uncertainty, it clearly has negative implications for the common religious concept of pre-determinism. The uncertainty principle not only shows we have free will, it also shows we cannot predict the future and the future is not pre-ordained. Since God would not disobey his own laws, God also cannot predict or preordain the future. The preordaining aspect of the world's religions is relegated to our spiritual brains. Our rational brains realize it is not possible.

The advent of quantum theory and the Heisenberg Uncertainty Principle put an end to the philosophy of determinism. Free will was restored to humans but at the price of having multiple and uncertain outcomes. Because of this uncertainty we cannot predict our future. Since God would not disobey his own laws, God also cannot predict or preordain the future.

Does Quantum Physics and Entanglement Support the Eastern Religious View of a Cosmic Consciousness Where All Parts of the Universe are Interconnected?

In his book, *The Tao of Physics,* Fritjof Capra [5] suggests there are parallels between quantum physics and Eastern mystic religions. Capra was trained in theoretical physics and became interested in Eastern mysticism. He confessed that overcoming the gap between his rational, analytical thinking and the meditative experience of mystical truth was very difficult. In a fashion somewhat similar to the theme of this book, Capra distinguishes between the rational brain and rational thought versus the mystical, spiritual, or intuitive brain and mystical thought.

> Rational knowledge is derived from the experience we have with objects and events in our everyday environment. It belongs to the realm of the intellect whose function it is to discriminate, divide, compare, measure, and categorize. In this way a world of intellectual distinctions is created. The realm of rational knowledge is, of course, the realm of science which measures and quantifies, classifies and analyzes.

This contrasts with what Buddhists call "absolute knowledge," a direct experience of reality which transcends not only intellectual thinking but also sensory perception. Eastern mystics insist that the ultimate reality can never be an object of reasoning or of demonstrable knowledge; it can never be adequately described by words, because it lies beyond the realm of the senses and of the intellect from which our words and concepts are derived. This is the basis of much of the meditative aspects of Eastern religions, where the basic aim is to silence the thinking mind and to shift the awareness from the rational to the intuitive mode of consciousness. When the rational mind is silenced, the intuitive mode produces an extraordinary awareness; the environment is experienced in a direct way without the filter of conceptual thinking.

This is the realm of the spiritual brain. Taoism is an ancient Chinese practice or tradition whose chief tenet is that there is a "Way" by which the universe flows, and that humans can learn to intuit this Way and live in accord with it or fight it.

So, what aspect of physics led Capra to conclude that it had a commonality with Eastern mystic religions? One aspect was that quantum theory and relativity theory, the two bases of modern physics, have made it clear that their reality transcends classical logic and we cannot talk about it in ordinary language. Capra states: [5p51]

> Probing inside the atom and investigating its structure, science transcended the limits or our sensory imagination. From this point on, it could no longer rely with absolute certainty on logic and common sense. Atomic physics provided scientists with the first glimpses of the essential nature of things. Like the mystics, physicists were now dealing with a nonsensory experience of reality and, like the mystics, they had to face the paradoxical aspects of this experience. From then on therefore, the models and images of modern physics became akin to those of Eastern philosophy.

Thus, Capra equates the weirdness of quantum theory and relativity with the mystic aspects of Eastern religions and as knowledge that is closer to the "absolute knowledge" of Buddhism than to the rational knowledge of Western thought. Even Einstein was shaken by this weirdness. He stated in his autobiography: [6]

> All my attempts to adapt the theoretical foundation of physics to this knowledge failed completely. It was as if the ground had been pulled out from under one, with no firm foundation to be seen anywhere, upon which one could have built.

There are a number of problems with Capra's concept of the unity of modern physics and Eastern mysticism. Capra leans heavily on Geoffrey Chew's 1970 "bootstrap" theory which attempted to do away with fundamental particles and replace them with the idea that every particle can be considered to be composed of other particles, with none more fundamental than any other. The success of the quark model, the Standard Theory, and M-theory all brought the bootstrap theory to a grinding halt. The demise of the bootstrap theory destroyed much of the apparent unity of modern physics with Eastern mysticism.

A second large part of the claim that modern physics and Eastern mysticism are similar is based on quantum entanglement. This assumes that if particles are instantly interconnected across the vastness of the universe, then all parts of the universe are connected to all other parts, just as proposed in Eastern religions. The problem with this is that information cannot be transmitted by quantum entanglement. All forms of communication, whether it is between societies, individuals, or within the nervous system of a single individual are based on a minimum of a one-way exchange of information and preferably a two-way exchange. If information cannot be

transmitted, the so-called cosmic connectedness or cosmic consciousness is a meaningless fantasy.

While Nobel laureate Murray Gell-Mann once jokingly stated that "physics is very Zen" he also opined that most of the pop science books on the subject are "New Age pap." These attempts to transform modern physics into new age mysticism all play on the weirdness of quantum physics and modern cosmology. When carefully examined, their metaphysical claims do not hold up well to the reality that *quantum theory provides some of the most ultra-precise predictions available in all of science — a far cry from the claim of Eastern mysticism that "ultimate reality can never be an object of reasoning or of demonstrable knowledge" or "that there is no real valid physical model of the world."*

> **Quantum entanglement has often been used to support the philosophy of Eastern religions of a cosmic consciousness in which all parts of the universe are interconnected. However, since information cannot be passed by entanglement, and since communication is the key to any meaningful interconnection, basing cosmic consciousness on quantum theory is a fantasy.**

Quantum Physics and Metaphysics

In his *Discourse on the Method,*[7] the French philosopher Rene Descartes stated, "I think, therefore I am." This has arguably become the most famous thought in the history of philosophy. Descartes believed that thinking and the awareness of thinking (consciousness) was the real essence of being. He believed that the thinking mind was separate from the nonthinking body. This is the philosophy of dualism, or the separation of mind and body. Monism is the opposite of dualism and proposes that the brain part of the body is the seat of the mind. The failure of dualism and evidence for monism was eloquently described in Antonio Damasio's book, *Descartes' Error.*[8] The entire modern field of neuroscience and cognitive science repeatedly validates the role of the brain in cognition and thinking.

Despite this, many recent books[9-13] continue to suggest there is some dimension of the mind that is beyond neurochemistry and physics. This is the realm of metaphysics which is concerned with the ultimate nature of reality. A variant of this is vitalism or transcendentalism, the philosophy that living processes cannot be explained in terms of their physical and chemical composition and processes. These philosophies are related by the ideas that the "whole is greater than the sum of its parts." In *Quantum Questions: Mystical Writings of the World's Great Physicists,* Ken Wilber[14] noted:

> Plato announced that the whole of physics was nothing more than a "likely story," since it depended ultimately on nothing but the evidence of the fleeting and shadowy senses, whereas truth resides in the transcendental forms beyond physics (hence "metaphysics"). Democritus,

> on the other hand, put his faith in the "atoms and the void," since nothing else, he felt, had any existence — a notion so obnoxious to Plato that he expressed the strongest desire that all the works of Democritus be burned on the spot.

This illustrates the truism that nothing under the sun changes. Now 2,000 years later, many still rail against the seeming inadequacy of science to explain "all there is." The weirder aspects of quantum theory provide a rich lode for mining by those who support this thought and they look to modern physics to validate their spiritual longings. As shown below, despite their own bents for mysticism, *none* of the major thinkers behind the modern physics revolution believed that relativity or quantum physics provided any support for these mystical and transcendental ideas.

2. The Big Bang

Do a Finite Universe and the Big Bang Prove God Exists?

Immanuel Kant (1724–1804) is considered to be the Father of Cosmology. Expanding on the work and ideas of Newton and other scientists of the time, he proposed a model of a mechanistic and infinite universe. He also swept away all earlier uses of cosmology to prove the existence of God. However, he was not an atheist. He was an agnostic and claimed that the question of God's existence was beyond the reach of man's knowledge. His views contributed greatly to materialism, determinism, and a number of other *isms,* including existentialism.[15p38] If the universe is infinite in time and space, with no starting time, no end, and no boundaries, as Kant proposed, then God was not the creator since the universe did not need to be created.[15p3] In his book, *A Brief History of Time,* Stephen Hawking states,

> If the universe is really completely self-contained, having no boundary or edge, it would have neither beginning nor end; it would simply be. What place then for a creator?

The famous astronomer, Fred Hoyle, also proposed a theory in which new matter was constantly being created, producing a universe with no beginning and no end — an infinite universe that just was.

By contrast to an infinite universe, if the universe is finite in time and space and if it was created out of nothing and has boundaries, this has been considered by many to provide proof that God exists,[15-18] since only God can create something from nothing. One or the other of these two concepts, a finite or an infinite universe, form the basis of most of the religions of the world. Western Christian, Jewish, and Muslim religions believe that God created the universe from nothing, while Eastern religions such as Buddhism and Hinduism propose a timeless universe with no beginning and no end. They also propose many levels of existence, with the highest being Nirvana. Nirvana is eternal and can only be attained by the purest of meditation.

Einstein's theory of relativity showed that Kant's model of an infinite universe was wrong. The Big Bang model, which is an extension of Einstein's theory, proposes that the universe originated from a singularity or a point of no size — nothing. Frederick Burnham, a science-historian, said of the Big Bang,

> These findings make the idea that God created the universe a more respectable hypothesis today than at any time in the last 100 years.

With a time scale that indicates the universe is 13.7 million years old, the Big Bang model is clearly not the view of the new earth creationists. With this exception, the Big Bang is a wonderful theory for theists since it is totally consistent with the view of God as the Creator. Eastern religions, by contrast, would agree with the new earth creationists but for opposite reasons, that the Big Bang is a seriously flawed bit of nonsense.

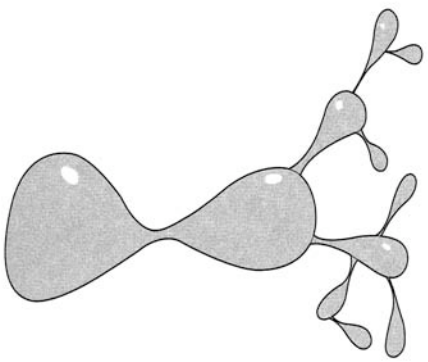

Figure 1. Budding multiverses. From Kaku. Parallel Worlds. [1] *By permission.*

In his book, *Parallel Worlds,* Michio Kaku, [1] whose parents were raised in the Buddhist tradition but who attended Sunday school and learned the parables of the Old Testament, proposed that there is theoretical evidence to support the existence of multiple universes or a multiverse in which entire universes continually sprout or "bud" off other universes.

If true, this would unify two of the great religious mythologies, Genesis of the Bible and Nirvana. Genesis would take place continually within the fabric of timeless Nirvana.

Our spiritual brain could choose to resolve this conflict between the philosophy of Eastern and Western religions either through multiverses or by suggesting that time and space are irrelevant to God. He is so powerful that He should be perfectly capable of creating either a finite or an infinite universe. By this view the Big Bang would not necessarily be proof that God exists and an endless universe would not be proof that God did not exist. Our rational brain could say that even this mental maneuvering is not really necessary.

> **While the scientific evidence for the Big Bang is overwhelming, the weirdness of quantum mechanics, or the collision of parallel universes, or the presence of multiverses, is sufficient to show how the inflation started and thus to explain the creation of the universe. No supernatural being is required.**

Is God Required to Stabilize the Universe?

After the publication of his *Principia,* Newton received a letter from the Reverend Richard Bentley. He asked Newton why gravity, which is always attractive, did not result in the collapse of the universe into itself. If the universe was finite it should end up as one giant fiery superstar. On the other hand, if the universe was infinite, then the force on any object tugging it right or left would be infinite, and the stars would be ripped to shreds. This was known as the *Bentley Paradox.* [1]

Newton's response to Bentley was that the universe was infinite and uniform such that the gravitational forces were evenly balanced, producing a stable universe. However, Newton realized the inadequacy of this response in that even the tiniest jiggle of a star would start a chain reaction of instability. Thus, his ultimate answer came from his spiritual brain and suggested that *a divine force was needed to prevent its collapse.* Newton suggested that while God created the universe, which then obeyed Newton's laws of gravity, God needed to intermittently intervene to keep the universe stable.

Had Newton known about dark energy, his rational brain could have provided the answer without needing God's help. Dark energy keeps the universe expanding at an accelerating rate, preventing its collapse. Of course it is somewhat embarrassing that science does not yet know what dark energy is. Theologians might say dark energy is the hand of God, designed to stabilize the universe. We currently do not know what dark energy is, but in time we will.

Einstein, who also did not know about dark energy, was also confronted with Bentley's paradox. Instead of using his spiritual brain and evoking God as Newton had done, he used his rational brain and added an anti-gravity force to his equations in the form of a *cosmological constant.* He also regretted this and called it "his greatest blunder" when Hubble showed the universe was expanding and the cosmological constant was not needed. After his death, when astronomers found that the universe was expanding at an accelerated rate, the cosmological constant was needed again. Einstein was right after all. Whether it is a cosmological constant or dark energy our rational brain can once again say to God, "Thanks, but I really don't need your help."

3. String Theory

Does String Theory Eliminate the Theological Advantage of the Big Bang?

Prior to string theory the Big Bang assumed that when the equations were run backward to the singularity point, the universe would be infinitely small, a point so small that the universe appeared to have developed from nothing—perfect for the religious view that God created the universe from nothing and that only God could do this.

String theory prevents the universe from being created from nothing. This effect is similar to the manner in which string theory solved a paradox of Newton's theory of gravity. In his famous inverse square law, the force of gravity, G, increased as the square of the decreasing distance. Thus $G = 1/r^2$, where r is the distance between the

bodies. The problem is that when this distance is zero, G is infinite. This problem was solved by string theory. Now r cannot be less than the size of a string, 10^{-33} centimeters and G is not infinite.

In the same vein, the universe did not arise from an infinitely small point it arose from something no smaller than a string. String theory places a limit on what was previously nothingness. While that limit is extremely small, 10^{-33} cm, it is not infinitely small. It is not nothing. Strings are not points; they have non-zero size. One could still ask, where did the strings come from? Did God create strings or have they always been there? The possibility that God and strings are the same is not very satisfactory, since ultra-minute strings do not provide for a very complex, warm, and fuzzy personal God. Strings are the simplest things in the universe. God is the most complex.

4. The Anthropic Principle

Does the Anthropic Principle Prove that God Exists?

Not everyone believes the Anthropic Principle is proof of design, or of Intelligent Design, or of the existence of God. There are a number of responses to the Anthropic Principle that do not require that type of interpretation.

The Anthropic Principle is just a tautology. A major criticism of the Anthropic Principle is that it is basically a *tautology,* or circular reasoning. Circular reasoning is a statement that is true by its own definition. In relation to the universe the tautology is that because we are here, we exist to ask the question. If we did not exist the question could not be asked. Or stated differently, if the features of the universe were incompatible with our existence, we would not be here to notice it.

The existence of many universes solves the Anthropic Principle. If we ignore the tautology and pursue the Anthropic Principle anyhow, the most common explanation is that the quantum fluctuations of space produce or attempt to produce billions of universes. Some have suggested up to 10^{500} [19] or untold trillions of universes. This has been referred to as a *megaverse,* a "huge landscape of possibilities—an enormously rich space of possible designs." [20] It is a mistake to think all of these other universes are as fully developed as ours. If a quantum instability began the birthing of a universe, but the constants were not right, it would never reach more than sub-microscopic proportions before it became extinct. Those latent universes that do not have the correct set of constants do not thrive. Those that do not have the right set of constants for life to exist do not have conscious beings capable of asking these questions. To Rees [21p247] the Anthropic Principle was one of the most compelling arguments for the multiverse. He commented,

> If the "constants" took different values in each universe, there would then be no need for surprise that some universes allowed creatures like us to exist. And we obviously find ourselves in one such subset. If you go to a clothes shop with a large stock of clothes, it isn't surprising to find a suit that fits you.

In their book *Origins,* Tyson and Goldsmith [22p99-104] argued that instead of providing evidence for God, the multi-universe proposal, which is an incredibly wasteful approach, clearly does not fit the concept of a perfect and efficient God.

Copernican Principle. The Copernican Principle is the opposite of the Anthropic Principle and states that humans do not occupy a privileged place in the universe. Successive astronomical discoveries seem to support this principle. In the Middle Ages it was assumed that God created man in his image, and as such, man and the earth were at the center of the universe. Copernicus and Galileo abolished the illusion that the earth was the center of the solar system and put the sun in its rightful heliocentric place. It was then found that the sun was not at the center of our galaxy, and Hubble showed that our own galaxy, the Milky Way, was not at the center of the universe. Finally, the multiverse concept suggests our universe may be just one of many constantly sprouting new universes, further diminishing the Anthropic Principle conclusion that the universe is here just for us. The Anthropic Principle emphasizes the rarity of life and consciousness while the Copernican Principle forces us to realize it was not all done just so we could exist.

There may be only a few or no true anthropic numbers. Carr and Rees [23] argued that although there appear to be a myriad number of so called anthropic coincidences or constants, only four are especially critical. These were *me* (mass of the electron), *mu* (mass of the up-quark), *md* (mass of the down-quark), and *g,* the Grand Unified coupling constant that determines the strength of the strong, electromagnetic, and weak forces. Taking this line of reasoning a step further, Kane and colleagues [24] proposed that:

> In string theories all of the parameters of the theory—in particular all quark and lepton masses, and all coupling strength—are calculable, so there are no parameters left to allow anthropic arguments…

Despite his sympathy for the concept of a God, Stephen Hawking's [25] latest studies also weigh in heavily against the Anthropic Principle. He proposed that our universe is much less "special" than the proponents of the Anthropic Principle claim it is. According to Hawking, *there is a 98 percent chance that a universe of a type as ours will come from the Big Bang.* Further, using the basic wave function of the universe as a basis, Hawking's equations indicate that such a universe can come into existence without relation to anything prior to it, meaning that it could come out of nothing.

The Anthropic Principle is a straw man, weakened by the fact that it is basically a tautology. It can be eliminated altogether by multiple universes, quantum mechanics and M-theory. The Anthropic Principle cannot be relied upon to prove that God exists.

The Participatory Anthropic Principle, Human Consciousness, and the Universe

In their opus on the Anthropic Principle, John Barrow and Frank Tipler [26] refer

to Wheeler's feedback loop connection between mankind and the universe as *PAP,* or the *Participatory Anthropic Principle.* This has been taken to the extreme of assuming that the process of creating reality by human observation is retroactive to the beginning of the universe. John Wheeler stated: [27p18]

> The Universe starts small at the Big Bang, grows in size, gives rise to life and observers and observing equipment. The observing equipment, in turn, through the elementary quantum processes that terminate on it, takes part in giving tangible "reality" to events that occurred long before there was any life anywhere.

This proposes that the universe creates man, but man through his observations of the universe brings the universe into reality. Martin Gardner [28] seems to have placed the anthropic principle in some perspective:

> What should one make of this quartet of WAP, SAP, PAP and FAP? In my not so humble opinion I think the last principle is best called CRAP, the Completely Ridiculous Anthropic Principle.

Wheeler himself recognized how bizarre the concept of PAP was. In the discussion of his article entitled "The Universe as Home for Man," [3p261] he states: [3p580]

> At first even the words sound absolutely ridiculous. After all, we know that the scale of man's existence is extraordinarily short compared with the whole time scale of the universe. So it is preposterous to think that life and mind in these few hundreds of thousands of years of self-conscious existence will have any control or influence over the development of the universe in the ten billions of years past and in the several tens of billions of years to come.

And yet later, when the discussion turned to the concept of a Darwinian evolution of multiple universes, he stated:

> The universe allows mutation and Darwinian natural selection to proceed; this Darwinian evolution leads to consciousness, and consciousness of consciousness; mind at this level gives meaning to the universe, and without mind at this level and "participation"… embodied in the quantum principle, the universe…could not have come into being in the first place. [3]

In essence, Wheeler tends to vacillate between two concepts. Few could argue about one while the other fits his own description of "sounding absolutely ridiculous." The ridiculous concept is: "The universe just would not exist if it were

not for consciousness to be aware of it." The similar, but drastically more acceptable concept, is: "The universe gives birth to consciousness; and consciousness gives meaning to the universe." The latter has an important kernel of wisdom—there is meaning to life that can be independently and naturally derived from human consciousness alone without requiring a divine power to provide that meaning.

There are two interpretations of the Participatory Anthropic Principle. One is ludicrous; the other is self-evident. One says, "The universe just would not exist if it were not for a human consciousness to be aware of it, and this effect is retroactive to the time of the Big Bang." This is the ludicrous one. The other says, "The universe gives birth to consciousness and consciousness gives meaning to the universe." This is the reasonable one and it has relevance to the issue of a meaning to life that can be independently and naturally derived from human consciousness alone, without requiring a divine power.

Science and Mysticism

In *Quantum Questions,* Ken Wilbur [14] notes that modern physics has been used to both support and refute determinism, free-will, God, Spirit, immortality, causality, predestination, Buddhism, Hinduism, Christianity, and Taoism. To help us lesser beings understand these issues, Wilbur collected the relevant opinions and writings from the cream of the creative thinkers in modern physics: Heisenberg, Schrödinger, Einstein, De Broglie, Jeans, Planck, Pauli, and Eddington.

> The last thing these theorists would want you to surrender is your critical intellect, your hard-earned skepticism. For it was exactly through a sustained use — not of emotion, not of intuition, not of faith — but a sustained use of the critical intellect that these greatest of physicists felt absolutely compelled to go beyond [the old] physics altogether.

All of these great scientists had a mystical bent and "were mystics of one sort or another." And yet to a man they were unanimous in their agreement that *modern physics offers no positive support whatsoever for mysticism or transcendentalism of any variety.* Thus, none of these great geniuses would support the seemingly infinite varieties of new age "pap" that have sprung up based on the findings of the "new physics."

The New Physics and Reality. Despite this strong conclusion, we still need to ask why each of these scientists felt a kinship to some form of mysticism based on their creation of the new physics. Part of the answer was that these physicists felt they were looking at nothing but a set of highly abstract differential equations — not at reality itself. They were looking at shadow symbols of reality. Sir James Jeans put it this way: [29]

> We can never understand what events are, but must limit ourselves to

> describing the patterns of events in mathematical terms; no other aim is possible. Physicists who are trying to understand nature may work in many different fields and by many different methods; one may dig, one may sow, one may reap. But the final harvest will always be a sheaf of mathematical formulae. These will never describe nature itself… our studies can never put us into contact with reality.

From this view science was at the opposite extreme of mysticism. Science deals with abstract symbols of reality, while mysticism deals with a direct, intuitive, faith based approach to reality itself. Thus, the claim that there are direct and central similarities between new physics and mysticism "represents a profound confusion of absolute and relative truth, of finite and infinite, of temporal and eternal." That is what repelled these physicists and led them to state that modern physics offers no support for mysticism.

This leads to the interesting question of what was the difference between the old physics and the new physics? The difference was profound. Both the old physics and the new physics dealt with shadow symbols, but the new physics *forced them to be aware that they were dealing with shadows and illusions, not reality.* With the new physics the shadowy character of the whole enterprise became much more obvious. It was this feeling that science was not yet in contact with reality that led the physicist to be sympathetic to mysticism in one form or another. It was the failure of the new physics to provide a total picture of reality, not similarities to mysticism, that led so many of the physicists to a mystical view of the world.

The alternate view of Murray Gell-Mann, who once characterized new age attempts to mysticize quantum physics as "flapdoodle," [30] stated that quantum theory provides some of the most ultra precise predictions available in all of science — a far cry from the claim of Eastern mysticism that ultimate reality can never be an object of reasoning or of demonstrable knowledge or that there is no real valid physical model of the world.

Gell-Mann was saying that simply because quantum mechanics is based on probabilities it does not make it less accurate. The new physics provides some of the most accurate predictions of reality ever conceived by man. If metaphysics is the search for the ultimate nature of reality, one could easily argue that based on the precision with which quantum theory predicts events in the micro-world and relativity theory predicts events in the macro-world—the ultimate reality has been found.

The philosophical and mystical views of the cream of the creative thinkers in modern physics show that most were unanimous in their agreement that modern physics offers no positive support for mysticism or transcendentalism of any variety. Despite this many had a mystical bent based on their feeling that the equations of physics may not represent the totality of reality. This illustrates the basic premise of this book — that humans with highly developed rational

brains can also have a well-developed sense of spirituality. However, other physicists disagree and correctly point out that the new physics provides an incredibly accurate prediction of reality, a picture that is far closer to the absolute truth than metaphysics could ever provide.

In conclusion, there is nothing in quantum mechanics, the theory of relativity, string theory, or the Anthropic Principle that provides proof of the existence of God, mysticism or transcendentalism. To the contrary, one could argue that quantum theory and string theory show us that the universe is capable of being created, if not from nothing, at least from almost nothing, without the need of divine intervention. These two theories certainly allow us to again use Occam's Razor to resolve the question: "Was the universe created as a consequence of features of quantum physics and M-theory, or was it created by God?" If the answer is that the universe was created by God, this again raises the infinitely more complex question of *Who Created God?* I suspect Occam would have chosen quantum physics as the creator of the universe.

There are, however, elements of the new physics that led many of the physics geniuses of the early twentieth century to feel that despite the incredible predictive power of quantum theory, they still only had a part of the total reality. Although some physicists disagree with this view, it is still clear that the spiritual brains of many scientists thirsted for more. This interaction between the rational versus the spiritual brain of these scientists is a reflection of the same conflict in everyone and is the core of the issues explored in the rest of this book.

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