

The Development of Life

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In this talk, I would like to speculate a little, on the development of life in the universe, and in particular, the development of intelligent life. I shall take this to include the human race, even though much of its behavior through out history, has been pretty stupid, and not calculated to aid the survival of the species. Two questions I shall discuss are, 'What is the probability of life existing else where in the universe?' and, 'How may life develop in the future?'

It is a matter of common experience that things get more disordered and chaotic with time. This observation can be elevated to the status of a law, the so-called Second Law of Thermodynamics. This says that the total amount of disorder, or entropy, in the universe, always increases with time. However, the Law refers only to the total amount of disorder. The order in one body can increase, provided that the amount of disorder in its surroundings increases by a greater amount. This is what happens in a living being. One can define Life to be an ordered system that can sustain itself against the tendency to disorder, and can reproduce itself. That is, it can make similar, but independent, ordered systems. To do these things, the system must convert energy in some ordered form, like food, sunlight, or electric power, into disordered energy, in the form of heat. In this way, the system can satisfy the requirement that the total amount of disorder increases, while, at the same time, increasing the order in itself and its offspring. A living being usually has two elements: a set of instructions that tell the system how to sustain and reproduce itself, and a mechanism to carry out the instructions. In biology, these two parts are called genes and metabolism. But it is worth emphasizing that there need be nothing biological about them. For example, a computer virus is a program that will make copies of itself in the memory of a computer, and will transfer itself to other computers. Thus it fits the definition of a living system, that I have given. Like a biological virus, it is a rather degenerate form, because it contains only instructions or genes, and doesn't have any metabolism of its own. Instead, it reprograms the metabolism of the host computer, or cell. Some people have questioned whether viruses should count as life, because they are parasites, and can not exist independently of their hosts. But then most forms of life, ourselves included, are parasites, in that they feed off and depend for their survival on other forms of life. I think computer viruses should count as life. Maybe it says something about human nature, that the only form of life we have created so far is purely destructive. Talk about creating life in our own image. I shall return to electronic forms of life later on.

What we normally think of as 'life' is based on chains of carbon atoms, with a few other atoms, such as nitrogen or phosphorous. One can speculate that one might have life with some other chemical basis, such as silicon, but carbon seems the most favourable case, because it has the richest chemistry. That carbon atoms should exist at all, with the properties that they have, requires a fine adjustment of physical constants, such as the QCD scale, the electric charge, and even the dimension of space-time. If these constants had significantly different values, either the nucleus of the carbon atom would not be stable, or the electrons would collapse in on the nucleus. At first sight, it seems remarkable that the universe is so finely tuned. Maybe this is evidence, that the universe was specially designed to produce the human race. However, one has to be careful about such arguments, because of what is known as the Anthropic Principle. This is based on the self-evident truth, that if the universe had not been suitable for life, we wouldn't be asking why it is so finely adjusted. One can apply the Anthropic Principle, in either its Strong, or Weak, versions. For the Strong Anthropic Principle, one supposes that there are many different universes, each with different values of the physical constants. In a small number, the values will allow the existence of objects like carbon atoms, which can act as the building blocks of living systems. Since we must live in one of these universes, we should not be surprised that the physical constants are finely tuned. If they weren't, we wouldn't be here. The strong form of the Anthropic Principle is not very satisfactory. What operational meaning can one give to the existence of all those other universes? And if they are separate from our own universe, how can

what happens in them, affect our universe. Instead, I shall adopt what is known as the Weak Anthropic Principle. That is, I shall take the values of the physical constants, as given. But I shall see what conclusions can be drawn, from the fact that life exists on this planet, at this stage in the history of the universe.

There was no carbon, when the universe began in the Big Bang, about 15 billion years ago. It was so hot, that all the matter would have been in the form of particles, called protons and neutrons. There would initially have been equal numbers of protons and neutrons. However, as the universe expanded, it would have cooled. About a minute after the Big Bang, the temperature would have fallen to about a billion degrees, about a hundred times the temperature in the Sun. At this temperature, the neutrons will start to decay into more protons. If this had been all that happened, all the matter in the universe would have ended up as the simplest element, hydrogen, whose nucleus consists of a single proton. However, some of the neutrons collided with protons, and stuck together to form the next simplest element, helium, whose nucleus consists of two protons and two neutrons. But no heavier elements, like carbon or oxygen, would have been formed in the early universe. It is difficult to imagine that one could build a living system, out of just hydrogen and helium, and anyway the early universe was still far too hot for atoms to combine into molecules.

The universe would have continued to expand, and cool. But some regions would have had slightly higher densities than others. The gravitational attraction of the extra matter in those regions, would slow down their expansion, and eventually stop it. Instead, they would collapse to form galaxies and stars, starting from about two billion years after the Big Bang. Some of the early stars would have been more massive than our Sun. They would have been hotter than the Sun, and would have burnt the original hydrogen and helium, into heavier elements, such as carbon, oxygen, and iron. This could have taken only a few hundred million years. After that, some of the stars would have exploded as supernovas, and scattered the heavy elements back into space, to form the raw material for later generations of stars.

Other stars are too far away, for us to be able to see directly, if they have planets going round them. But certain stars, called pulsars, give off regular pulses of radio waves. We observe a slight variation in the rate of some pulsars, and this is interpreted as indicating that they are being disturbed, by having Earth sized planets going round them. Planets going round pulsars are unlikely to have life, because any living beings would have been killed, in the supernova explosion that led to the star becoming a pulsar. But, the fact that several pulsars are observed to have planets suggests that a reasonable fraction of the hundred billion stars in our galaxy may also have planets. The necessary planetary conditions for our form of life may therefore have existed from about four billion years after the Big Bang.

Our solar system was formed about four and a half billion years ago, or about ten billion years after the Big Bang, from gas contaminated with the remains of earlier stars. The Earth was formed largely out of the heavier elements, including carbon and oxygen. Somehow, some of these atoms came to be arranged in the form of molecules of DNA. This has the famous double helix form, discovered by Crick and Watson, in a hut on the New Museum site in Cambridge. Linking the two chains in the helix, are pairs of nucleic acids. There are four types of nucleic acid, adenine, cytosine, guanine, and thiamine. I'm afraid my speech synthesiser is not very good, at pronouncing their names. Obviously, it was not designed for molecular biologists. An adenine on one chain is always matched with a thiamine on the other chain, and a guanine with a cytosine. Thus the sequence of nucleic acids on one chain defines a unique, complementary sequence, on the other chain. The two chains can then separate and each act as templates to build further chains. Thus DNA molecules can reproduce the genetic information, coded in their sequences of nucleic acids. Sections of the sequence can also be used to make proteins and other chemicals, which can carry out the instructions, coded in the sequence, and assemble the raw material for DNA to reproduce itself.

We do not know how DNA molecules first appeared. The chances against a DNA molecule arising by random fluctuations are very small. Some people have therefore suggested that life came to Earth from elsewhere, and that there are seeds of life floating round in the galaxy. However, it seems unlikely that DNA could survive for long in the radiation in space. And even if it could, it would not really help explain the origin of life, because the time available since the formation of carbon is only just over double the age of the Earth.

One possibility is that the formation of something like DNA, which could reproduce itself, is extremely unlikely. However, in a universe with a very large, or infinite, number of stars, one would expect it to occur in a few stellar systems, but they would be very widely separated. The fact that life happened to occur on Earth, is not however surprising or unlikely. It is just an application of the Weak Anthropic Principle: if life had appeared instead on another planet, we would be asking why it had occurred there.

If the appearance of life on a given planet was very unlikely, one might have expected it to take a long time. More precisely, one might have expected life to appear just in time for the subsequent evolution to intelligent beings, like us, to have occurred before the cut off, provided by the life time of the Sun. This is about ten billion years, after which the Sun will swell up and engulf the Earth. An intelligent form of life, might have mastered space travel, and be able to escape to another star. But otherwise, life on Earth would be doomed.

There is fossil evidence, that there was some form of life on Earth, about three and a half billion years ago. This may have been only 500 million years after the Earth became stable and cool enough, for life to develop. But life could have taken 7 billion years to develop, and still have left time to evolve to beings like us, who could ask about the origin of life. If the probability of life developing on a given planet, is very small, why did it happen on Earth, in about one 14th of the time available.

The early appearance of life on Earth suggests that there's a good chance of the spontaneous generation of life, in suitable conditions. Maybe there was some simpler form of organisation, which built up DNA. Once DNA appeared, it would have been so successful, that it might have completely replaced the earlier forms. We don't know what these earlier forms would have been. One possibility is RNA. This is like DNA, but rather simpler, and without the double helix structure. Short lengths of RNA, could reproduce themselves like DNA, and might eventually build up to DNA. One can not make nucleic acids in the laboratory, from non-living material, let alone RNA. But given 500 million years, and oceans covering most of the Earth, there might be a reasonable probability of RNA, being made by chance.

As DNA reproduced itself, there would have been random errors. Many of these errors would have been harmful, and would have died out. Some would have been neutral. That is they would not have affected the function of the gene. Such errors would contribute to a gradual genetic drift, which seems to occur in all populations. And a few errors would have been favourable to the survival of the species. These would have been chosen by Darwinian natural selection.

The process of biological evolution was very slow at first. It took two and a half billion years, to evolve from the earliest cells to multi-cell animals, and another billion years to evolve through fish and reptiles, to mammals. But then evolution seemed to have speeded up. It only took about a hundred million years, to develop from the early mammals to us. The reason is, fish contain most of the important human organs, and mammals, essentially all of them. All that was required to evolve from early mammals, like lemurs, to humans, was a bit of fine-tuning.

But with the human race, evolution reached a critical stage, comparable in importance with the development of DNA. This was the development of language, and particularly written language. It

meant that information can be passed on, from generation to generation, other than genetically, through DNA. There has been no detectable change in human DNA, brought about by biological evolution, in the ten thousand years of recorded history. But the amount of knowledge handed on from generation to generation has grown enormously. The DNA in human beings contains about three billion nucleic acids. However, much of the information coded in this sequence, is redundant, or is inactive. So the total amount of useful information in our genes, is probably something like a hundred million bits. One bit of information is the answer to a yes no question. By contrast, a paper back novel might contain two million bits of information. So a human is equivalent to 50 Mills and Boon romances. A major national library can contain about five million books, or about ten trillion bits. So the amount of information handed down in books, is a hundred thousand times as much as in DNA.

Even more important, is the fact that the information in books, can be changed, and updated, much more rapidly. It has taken us several million years to evolve from the apes. During that time, the useful information in our DNA, has probably changed by only a few million bits. So the rate of biological evolution in humans, is about a bit a year. By contrast, there are about 50,000 new books published in the English language each year, containing of the order of a hundred billion bits of information. Of course, the great majority of this information is garbage, and no use to any form of life. But, even so, the rate at which useful information can be added is millions, if not billions, higher than with DNA.

This has meant that we have entered a new phase of evolution. At first, evolution proceeded by natural selection, from random mutations. This Darwinian phase, lasted about three and a half billion years, and produced us, beings who developed language, to exchange information. But in the last ten thousand years or so, we have been in what might be called, an external transmission phase. In this, the internal record of information, handed down to succeeding generations in DNA, has not changed significantly. But the external record, in books, and other long lasting forms of storage, has grown enormously. Some people would use the term, evolution, only for the internally transmitted genetic material, and would object to it being applied to information handed down externally. But I think that is too narrow a view. We are more than just our genes. We may be no stronger, or inherently more intelligent, than our cave man ancestors. But what distinguishes us from them, is the knowledge that we have accumulated over the last ten thousand years, and particularly, over the last three hundred. I think it is legitimate to take a broader view, and include externally transmitted information, as well as DNA, in the evolution of the human race.

The time scale for evolution, in the external transmission period, is the time scale for accumulation of information. This used to be hundreds, or even thousands, of years. But now this time scale has shrunk to about 50 years, or less. On the other hand, the brains with which we process this information have evolved only on the Darwinian time scale, of hundreds of thousands of years. This is beginning to cause problems. In the 18th century, there was said to be a man who had read every book written. But nowadays, if you read one book a day, it would take you about 15,000 years to read through the books in a national Library. By which time, many more books would have been written.

This has meant that no one person can be the master of more than a small corner of human knowledge. People have to specialise, in narrower and narrower fields. This is likely to be a major limitation in the future. We certainly can not continue, for long, with the exponential rate of growth of knowledge that we have had in the last three hundred years. An even greater limitation and danger for future generations, is that we still have the instincts, and in particular, the aggressive impulses, that we had in cave man days. Aggression, in the form of subjugating or killing other men, and taking their women and food, has had definite survival advantage, up to the present time. But now it could destroy the entire human race, and much of the rest of life on Earth. A nuclear war, is still the most immediate danger, but there are others, such as the

release of a genetically engineered virus. Or the green house effect becoming unstable.

There is no time, to wait for Darwinian evolution, to make us more intelligent, and better natured. But we are now entering a new phase, of what might be called, self designed evolution, in which we will be able to change and improve our DNA. There is a project now on, to map the entire sequence of human DNA. It will cost a few billion dollars, but that is chicken feed, for a project of this importance. Once we have read the book of life, we will start writing in corrections. At first, these changes will be confined to the repair of genetic defects, like cystic fibrosis, and muscular dystrophy. These are controlled by single genes, and so are fairly easy to identify, and correct. Other qualities, such as intelligence, are probably controlled by a large number of genes. It will be much more difficult to find them, and work out the relations between them. Nevertheless, I am sure that during the next century, people will discover how to modify both intelligence, and instincts like aggression.

Laws will be passed, against genetic engineering with humans. But some people won't be able to resist the temptation, to improve human characteristics, such as size of memory, resistance to disease, and length of life. Once such super humans appear, there are going to be major political problems, with the unimproved humans, who won't be able to compete. Presumably, they will die out, or become unimportant. Instead, there will be a race of self-designing beings, who are improving themselves at an ever-increasing rate.

If this race manages to redesign itself, to reduce or eliminate the risk of self-destruction, it will probably spread out, and colonise other planets and stars. However, long distance space travel, will be difficult for chemically based life forms, like DNA. The natural lifetime for such beings is short, compared to the travel time. According to the theory of relativity, nothing can travel faster than light. So the round trip to the nearest star would take at least 8 years, and to the centre of the galaxy, about a hundred thousand years. In science fiction, they overcome this difficulty, by space warps, or travel through extra dimensions. But I don't think these will ever be possible, no matter how intelligent life becomes. In the theory of relativity, if one can travel faster than light, one can also travel back in time. This would lead to problems with people going back, and changing the past. One would also expect to have seen large numbers of tourists from the future, curious to look at our quaint, old-fashioned ways.

It might be possible to use genetic engineering, to make DNA based life survive indefinitely, or at least for a hundred thousand years. But an easier way, which is almost within our capabilities already, would be to send machines. These could be designed to last long enough for interstellar travel. When they arrived at a new star, they could land on a suitable planet, and mine material to produce more machines, which could be sent on to yet more stars. These machines would be a new form of life, based on mechanical and electronic components, rather than macromolecules. They could eventually replace DNA based life, just as DNA may have replaced an earlier form of life.

This mechanical life could also be self-designing. Thus it seems that the external transmission period of evolution, will have been just a very short interlude, between the Darwinian phase, and a biological, or mechanical, self design phase. This is shown on this next diagram, which is not to scale, because there's no way one can show a period of ten thousand years, on the same scale as billions of years. How long the self-design phase will last is open to question. It may be unstable, and life may destroy itself, or get into a dead end. If it does not, it should be able to survive the death of the Sun, in about 5 billion years, by moving to planets around other stars. Most stars will have burnt out in another 15 billion years or so, and the universe will be approaching a state of complete disorder, according to the Second Law of Thermodynamics. But Freeman Dyson has shown that, despite this, life could adapt to the ever-decreasing supply of ordered energy, and therefore could, in principle, continue forever.

What are the chances that we will encounter some alien form of life, as we explore the galaxy. If the argument about the time scale for the appearance of life on Earth is correct, there ought to be many other stars, whose planets have life on them. Some of these stellar systems could have formed 5 billion years before the Earth. So why is the galaxy not crawling with self designing mechanical or biological life forms? Why hasn't the Earth been visited, and even colonised. I discount suggestions that UFO's contain beings from outer space. I think any visits by aliens, would be much more obvious, and probably also, much more unpleasant.

What is the explanation of why we have not been visited? One possibility is that the argument, about the appearance of life on Earth, is wrong. Maybe the probability of life spontaneously appearing is so low, that Earth is the only planet in the galaxy, or in the observable universe, in which it happened. Another possibility is that there was a reasonable probability of forming self reproducing systems, like cells, but that most of these forms of life did not evolve intelligence. We are used to thinking of intelligent life, as an inevitable consequence of evolution. But the Anthropic Principle should warn us to be wary of such arguments. It is more likely that evolution is a random process, with intelligence as only one of a large number of possible outcomes. It is not clear that intelligence has any long-term survival value. Bacteria, and other single cell organisms, will live on, if all other life on Earth is wiped out by our actions. There is support for the view that intelligence, was an unlikely development for life on Earth, from the chronology of evolution. It took a very long time, two and a half billion years, to go from single cells to multi-cell beings, which are a necessary precursor to intelligence. This is a good fraction of the total time available, before the Sun blows up. So it would be consistent with the hypothesis, that the probability for life to develop intelligence, is low. In this case, we might expect to find many other life forms in the galaxy, but we are unlikely to find intelligent life. Another way, in which life could fail to develop to an intelligent stage, would be if an asteroid or comet were to collide with the planet. We have just observed the collision of a comet, Schumacher-Levi, with Jupiter. It produced a series of enormous fireballs. It is thought the collision of a rather smaller body with the Earth, about 70 million years ago, was responsible for the extinction of the dinosaurs. A few small early mammals survived, but anything as large as a human, would have almost certainly been wiped out. It is difficult to say how often such collisions occur, but a reasonable guess might be every twenty million years, on average. If this figure is correct, it would mean that intelligent life on Earth has developed only because of the lucky chance that there have been no major collisions in the last 70 million years. Other planets in the galaxy, on which life has developed, may not have had a long enough collision free period to evolve intelligent beings.

A third possibility is that there is a reasonable probability for life to form, and to evolve to intelligent beings, in the external transmission phase. But at that point, the system becomes unstable, and the intelligent life destroys itself. This would be a very pessimistic conclusion. I very much hope it isn't true. I prefer a fourth possibility: there are other forms of intelligent life out there, but that we have been overlooked. There used to be a project called SETI, the search for extra-terrestrial intelligence. It involved scanning the radio frequencies, to see if we could pick up signals from alien civilisations. I thought this project was worth supporting, though it was cancelled due to a lack of funds. But we should have been wary of answering back, until we have develop a bit further. Meeting a more advanced civilisation, at our present stage, might be a bit like the original inhabitants of America meeting Columbus. I don't think they were better off for it.

That is all I have to say. Thank you for listening.