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The origin of life

In the beginning...

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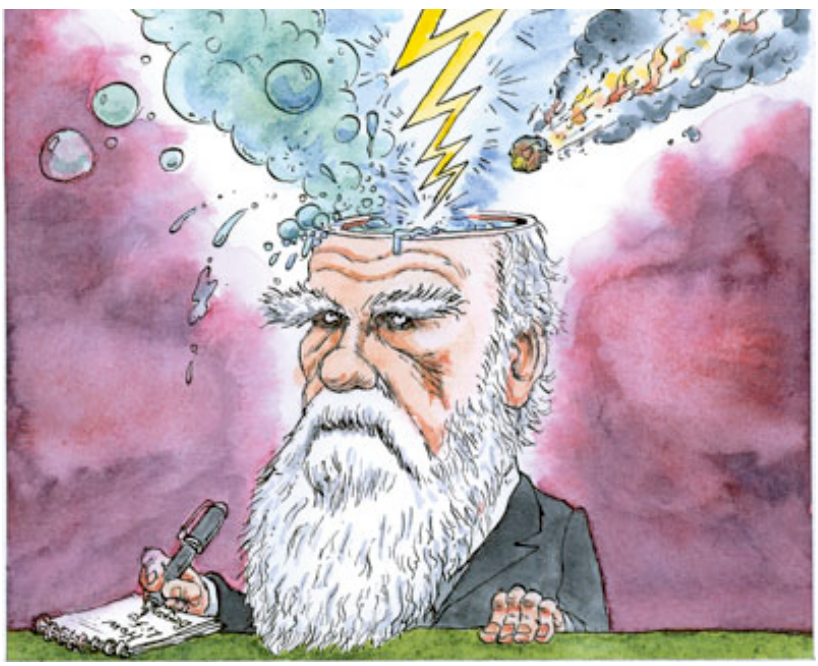
How life on Earth got going is still mysterious, but not for want of ideas



NEVER make forecasts, especially about the future. Samuel Goldwyn's wise advice is well illustrated by a pair of scientific papers published in 1953. Both were thought by their authors to be milestones on the path to the secret of life, but only one has so far amounted to much, and it was not the one that caught the public imagination at the time.

James Watson and Francis Crick, who wrote “A structure for deoxyribose nucleic acid”, have become as famous as rock stars for asking how life works and thereby starting a line of inquiry that led to the Human Genome Project. Stanley Miller, by contrast, though lauded by his peers, languishes in obscurity as far as the wider world is concerned. Yet when it appeared, “Production of amino acids under possible primitive Earth conditions” was expected to begin a scientific process that would solve a problem in some ways more profound than how life works at the moment—namely how it got going in the first place on the surface of a sterile rock 150m km from a small, unregarded yellow star.

Dr Miller was the first to address this question experimentally. Inspired by one of Charles Darwin's ideas, that the ingredients of life might have formed by chemical reactions in a “warm, little pond”, he mixed the gases then thought to have formed the atmosphere of the primitive Earth—methane, ammonia and hydrogen—in a flask half-full of boiling water, and passed electric sparks, mimicking lightning, through them for several days to see what would happen. What happened, as the name of the paper suggests, was amino acids, the building blocks of proteins. The origin of life then seemed within grasp. But it has eluded researchers ever since. They are still looking, though, and this week several of them met at the Royal Society, in London, to review progress.

The origin of pieces

The origin question is really three sub-questions. One is, where did the raw materials for life come from? That is what Dr Miller was asking. The second is, how did those raw materials spontaneously assemble themselves into the first object to which the term “alive” might reasonably be applied? The third is, how, having once come into existence, did it survive conditions in the early solar system?

The first question was addressed by Patrick Thaddeus, of the Harvard-Smithsonian Centre for Astrophysics, and Max Bernstein, who works at the Ames laboratory, in California, part of America's space agency, NASA. As Dr Bernstein succinctly put it, the chemical raw materials for life, in the form of simple compounds that could then be assembled into more complex biomolecules, could come from above, below or beyond.

The “above” theory—ie, that the raw materials were formed in the atmosphere, and which Dr Miller's original experiment was intended to investigate—has fallen out of favour. That is because it depends on the atmosphere being composed of chemicals rich in hydrogen, which methane and ammonia are. Dr Miller thought this was likely because it was known in the 1950s that Jupiter's atmosphere contains these gases. Modern thinking, though, favours an early terrestrial atmosphere rich in carbon dioxide, as is found on Venus and Mars. Such an atmosphere is no good for making amino acids.

The “beyond” theory is that the raw materials were formed in space, and came to Earth either while it was being formed, or in the form of a later chemical “top up” from comets and interstellar dust. Dr Thaddeus waxed eloquent in support of this, pointing out that radio astronomy has now identified 135 different molecules in outer space (each gives out a specific pattern of radio waves when its atoms are shaken, allowing it to be identified from afar). Moreover, these molecules tend to be concentrated in the sorts of nebulae in which stars and their associated planetary systems are known to form.

Sadly, though, few of the 135 chemicals found so far resemble any important building block of life. That leaves the “below” hypothesis, which is the one Dr Bernstein favours. His theory is that the crucial raw materials were built up in hydrothermal vents like those found today in the deep ocean. These do, indeed, leak chemicals of the sort that Dr Miller used, though they provide reaction-encouraging energy in the form of heat alone, with no electricity. Nevertheless, modern vents do seem to produce not only simple amino acids but also short amino-acid chains—in other words, tiny proteins.

Going from the raw materials to the finished product, though, is a big step. In this case, the definition of “finished product” is something that is recognisably the ancestor of life today. Such an ancestor would store information in DNA, or a molecule similar to it, that was able to replicate, and thus breed. It would also use that information to make proteins. And it would probably do all this inside a membrane made of fatty molecules. In other words, it would be a living cell.

Worlds without end

The favoured theory at the moment is that the first genetic material was not DNA, but its cousin RNA. In the wake of the Watson and Crick paper, a series of experiments showed that RNA acts as a messenger for the DNA, and as a fetcher and carrier of amino acids for the factories in which proteins are made. Until recently, therefore, it was seen as a rather humble substance—a molecular hewer of wood and drawer of water for the presiding DNA genius in the cell nucleus. But it is also an important component of the protein factories themselves. Indeed, these factories are known as ribosomes because of it. And the past few years have seen the discovery of more and more roles for RNA, including some in which it acts as a chemical catalyst—a job that had previously been thought to be restricted to protein-based enzymes.

This ubiquity, combined with the fact that RNA can catalyse chemical reactions, has led to the idea of an RNA world that preceded the modern DNA/protein world—and it seems very likely that RNA did, indeed, precede DNA, if only because it is the more chemically stable of the two. But that does not explain either where the RNA came from in the first place, or how the RNA/protein interdependence came about—a question known as the "breakout" problem.

There are several ideas for how large molecules such as RNA (and also early proteins) might have been generated out of the chemical raw materials that came from above or below or beyond. Two of the most persistent, though, are that clay was the catalyst, and that iron and nickel sulphides were the catalysts.

The clay theory is widely held, but needs tightening up. James Ferris of Rensselaer Polytechnic Institute, in New York state, explained to the meeting that his research on a type of clay called montmorillonite showed that it catalysed the formation of RNA molecules up to 50 units long. (A unit, in this context, is one of the four chemical bases that make up the alphabet of the genetic code, attached to some sugar and phosphate.) He also showed that the process was selective, with the same relatively small set of RNA molecules emerging every time. That is important, because if all possible permutations of the four bases were equally likely, none of them would ever become common enough for anything interesting to happen.

The iron/nickel/sulphur model is the brainchild of Günter Wächtershauser of Munich University. It, too, relies on catalysis, though in this case the best-tested chemical pathways generate amino acids and proteins, rather than RNA. Unfortunately, neither the clay route nor the iron/nickel route answers the breakout question. But a third, and novel, model described at the meeting might.

This was devised by Trevor Dale of Cardiff University, in Wales. He has come up with a way that proteins and RNA might catalyse each other's production.

The protein involved would crystallise in the form of long, and easily formed, fibres called amyloid. (This is the form that proteins take in brain diseases such as Alzheimer's and Creutzfeldt-Jakob.) The amyloid fibres would then act as surfaces on which RNA molecules could grow.

Crucially, RNA forming on a fibre this way would grow as double strands, like the DNA in a cell nucleus, rather than as the single strands in which the molecule normally comes. When the strands separated, each would act as a template for a new double-stranded molecule, just as happens when a DNA molecule divides.

The protein, meanwhile, would grow because the protruding end of the RNA would act as a catalyst, adding amino acids on to the end of the amyloid fibre. When the fibre grew too long to be stable, it would break in two. Thus both RNA and protein would replicate.

Such a system, Dr Dale thinks, could be the ancestor of the ribosome and, if wrapped in a fatty membrane, of the cell. And, as David Deamer, of the University of California, Santa Cruz, told the meeting, such membranes will assemble spontaneously in certain conditions.

Dr Dale's idea is certainly chemically plausible, though it has yet to be tested in a laboratory. But he is conducting tests at the moment, and hopes to have the results later this year.

The third sub-question—of how life managed to get going at all in the hostile arena of the early Earth, was neatly addressed by Charles Cockell, of Britain's Open University. The perceived problem is that for the first 600m years of its existence, the planet was being bombarded by bits of debris left over from the formation of the solar system. Yet chemical signatures in the few rocks left over from this period suggest that life—presumably in the form of bacteria—was well established by the end of it. How, then, did that life survive the constant rain of asteroids?

Beginnings are such delicate times

Dr Cockell turned the question neatly on its head by showing that impact craters are ideal places for life to get going. The heat generated by an impact produces local hydrothermal springs. These start off hot, thus favouring the formation of amino acids and RNA-forming bases. They then cool over the centuries to the point where these individual molecules can get together in more complex chains. And they also have lots of microscopic nooks and crannies with space for micro-organisms to breed, and interesting chemicals in them for bugs to feed on.

The biggest irony of all, then, might be that the conditions once thought a near-insuperable obstacle to the emergence of life on Earth may actually have enabled it to come about.