Max Coleman, introducing “How, on Earth, did life begin?”

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What is life?’ At its most basic, life on Earth is a collection of amino acids.

Why did it begin? One answer is that it is because it is a very efficient way of getting rid of excess chemical energy.

There are many chemical reactions on Earth which could not happen without life e.g. the amount of energy released by perchlorate reacting with organic matter to produce chlorate is very considerable. Another example is the fact that in normal circumstances, the reaction of sulfate with organic matter to produce sulfide does not happen because there is an activation energy barrier; however, microbes have metabolic pathways and act as enzymes to enable that reaction to go forward, and hence take advantage of the energy released. On Mars, there is a large amount of perchlorate on the surface, while on Earth, perchlorate only accumulates in very rare, dry places like the Atacama Desert, and the reason for this is that perchlorate digesting bacteria get to work on it and reduce it. Hence one may reasonably conclude that there is indeed an absence of life on Mars.

So how did life begin? There is still no answer to this! However, it is clear that the early Earth arose from the accumulation of dust and planetesimals plus organic molecules, and in due course a change from abiotic chemistry to what one may call pre-biotic chemistry, occurred, and at some stage this led to self-replicating molecular compounds in what is known as the RNA world, and from that to the DNA or protein world (in protein soups or broths?) and eventually the genetic code.

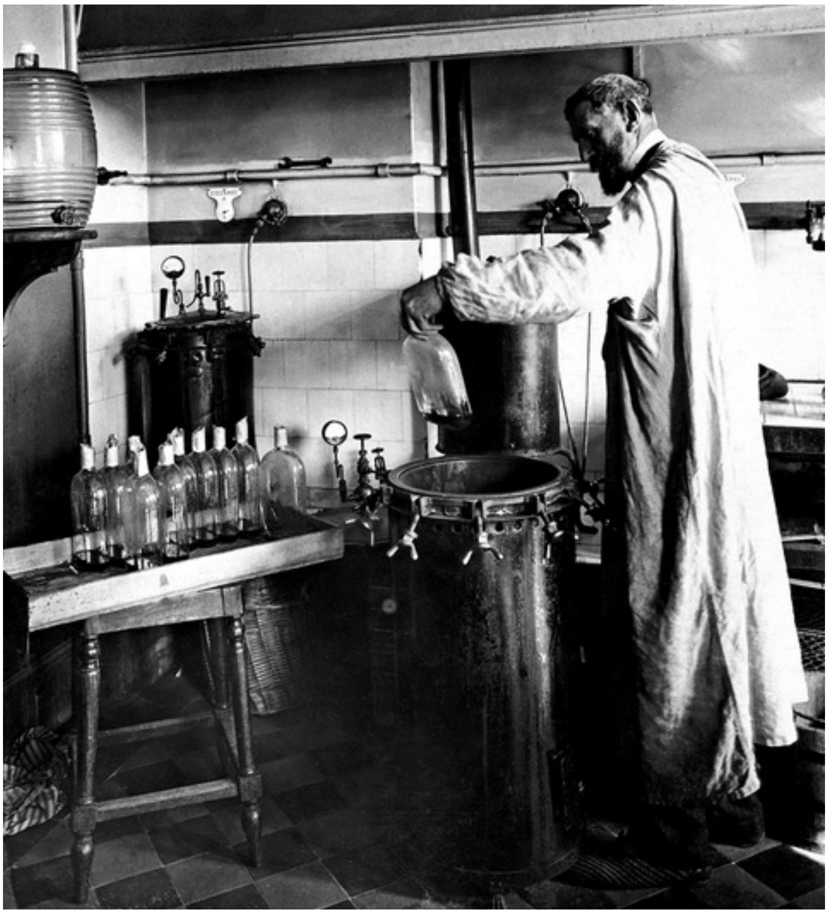
Max then focussed on the time between the formation of the Earth and the acquisition of complex organic molecules.

So, returning to what is life? Generally, it is regarded as comprising 20 amino acids (plus a couple more which can be synthesised) which can be regarded as the ‘building blocks’ of life.

The early history of research in this area is the famous Miller-Urey paper published in *Science* in 1953, a year before Miler finished his thesis! The paper was a mere one and a half pages, titled ‘The production of amino acids under possible primitive Earth conditions’ (using an ‘atmosphere’ of methane, ammonia, water and hydrogen with an electric discharge) in which he made glycine, a two-carbon amino acid, and alanine, another simple amino acid. [Urey was a brilliant scientist and discovered that stable isotopes could be used to determine palaeotemperatures].

The Urey-Miller experiment that produced amino acids from inorganic starter gases (atmosphere) with electrical discharge (lightning):

The signature of life - left handed molecules exemplified by those first discovered by Louis Pasteur in his research on tartaric acid in wine:



Do we need to make amino acids here on Earth or did they arrive from space (since they occur in large amounts in carbonaceous chondrites)? Following on from Louis Pasteur's work material in wine bottles, he showed that there were two forms of tartaric acid – which changed the direction of polarised light in opposite ways i.e. left and right-hand structures – and this is relatively common among organic molecules. Of the 20 amino acid molecules in life, all are left-handed. Consequently, all R-handed amino acids are non-life related. In the chondrites, 96 amino acids have been detected, including glycine. So, there is at least the possibility of amino acids having been deposited on the early Earth.

One investigator, John Sutherland, Prof of Chemistry at the Univ. of Cambridge, found that hydrogen cyanide (HCN) is a useful starting material if you want to generate amino acids! The early Earth would have had both hydrogen and nitrogen in the atmosphere and with high energy input from intense UV, lightning, solar flares or meteorite impacts, some very stable, diatomic species like CO, CN and NO, could have been produced. While all these are very resilient but they can be broken down at high temperature (e.g. igneous activity) to produce HCN and even formaldehyde (HCOOH). In addition, HCN plus H_2S can produce two and three carbon sugars which would have been useful for the origin of life, and if you need to concentrate the CN this can be done by reaction with iron to produce ferrocyanide (which may have accumulated in temporary or long-lived lakes in high concentrations).

Mike Russell, a colleague at JPL, who has investigated submarine hydrothermal vents as a potential place for the origin of life, specifically via the precipitation of 'mineral bubbles' as precursors of cells and co-opting transition elements as enzymes (which can be traced back very far in the genetic tree).

A third option was determined by organic chemist, Harold Helgeson, who determined the thermodynamic constants for amino acids, and found that of the amino acids, those used by Life were perhaps the easiest and most stable of organic compounds to make.

And finally, panspermia, originated by Fred Hoyle and Wickramasinghe who proposed that amino acids were created in the dust in the galaxy, and also suggested that pandemics on Earth (like flu) resulted from the Earth going through a cloud of viruses, formed elsewhere, and falling onto the Earth. Amazingly, panspermia is still referred to in publications.

Max concluded with a summary of the options are for the origin of life as:

1. Fallout on the Earth from space
2. Made on the early Earth in shallow lakes by cyanide related processes
3. Made on the early Earth from within hydrothermal vents and finally,
4. Panspermia.

DISCUSSION

Q. Recent news included reports of bacteria on Venus.
A. Max had not been persuaded of the validity of these reports, or of supposed evidence of methane on Mars.

Q. Does space exploration have any benefits for understanding the origin of life on Earth?
A. Yes, because for the terrestrial planets, particularly Mars, there would have been the potential for life to have originated there. For the icy moons of the outer planets, life could have originated there on hydrothermal vents but at a different time, to Earth perhaps in the deep ocean on Europa.

Q. Is there any possibility of contamination from Earth onto other planets or the reverse? A. Yes, and so there is a very large sense of bio-protection against contamination on each planetary mission. And when lunar soil was first brought back to Earth, it was fed to chickens to see if it had any adverse effect on them!

Q. Given the simplicity of the definition of life, would one not expect to see that it had originated at many, many places in the universe?
A. Yes one would which is why this discussion is based on life on Earth rather than on selenium carbide-based life somewhere else!! But one of the ways that exoplanets are being examined for potential life is to see if, contrary to expectations, there appears to be kinetic based reactions happening in their atmospheres.

It was noted that on 22 Aug in the Economist there had been an excellent article on the impact of viruses throughout human evolution, which members may wish to follow up. Similarly, a few years ago, the impact of viruses on microbial evolution had been published, and that had literally been world changing.

Q. How inevitable was it if you have Earth-like conditions, that life would evolve.
A. The real difficulty is that astrobiology is a very big topic and there are many peer reviewed papers which are scientifically quite sloppy, that to get a subset of possible ways in which life could have originated is very, very difficult, with many 'conjecture' papers.

Q. Could Max please clarify the significance of the 20 amino acids which are the basis of life on Earth and (are all L-type) occur naturally on Earth compared to the 96 which are found on carbonaceous chondrites? And what is the significance of the Left (Levo) or Right-handed (Dextro) nature of the molecules concerned?
A. Large numbers of amino acids were made abiotically in the early solar system. Life when it started evolving and reproducing itself, chose Left, and all life uses this form. The energy difference between L and D is negligible, but once the natural selection process began, then life continued to use the L form. However, there are some bacteria which can produce D type amino acids as a coating on their bodies to deter predators who will think that they are not edible, which is distinctly unusual.

Q. In terms of the thermodynamics, would the deep ocean hydrothermal vents not be the preferred place for the origin of life on Earth compare to the surface?

A. UV at the surface can be deadly for life on the surface, but early life forms could have been protected within mud in shallow lakes and concentrated around ferrocycanide, as John Sutherland has shown.

Q. Life seems to have appeared within the first half a billion years of Earth history; did life originate just once or at various times through geologic time? Was it a one-off process or did it happen over and over again?
A. Yes, during the development of heredity and the amino acids being produced, many parallel evolutions could have occurred. But as soon as one is successful, natural selection is such that it would have defeated all the others. And not forgetting that of course, the further back in time you go, there is less and less evidence. For example, the very old stromatolites are very few and far between, and the carbon isotope compositions of very old graphite (e.g. Jack Hills samples) are disputed but nonetheless they suggest that biological processes could have occurred. It would be very nice if there was a tell-tale marker of where life had begun but failed!

Q. How did heredity begin?
A. Potentially, this began before life itself with a biochemical catalyst or non-biological enzyme, which allowed a reaction to go ahead, is a first step.

Q. Can there be life without heredity?
A. It is really what we mean by life, in terms of being able to reproduce itself, even without evolving, otherwise it might have lasted one generation and unable to continue.

Q. In natural selection, one form of life is competing with another. In the earliest form of life, what would have been the competition?
A. With each other for the protein rich broth i.e. territory and resources in effect, potentially on a hydrothermal vent either in a micro-environment or even on an oceanic scale.

Q. What kind of evidence are you expecting to find on Mars with the ‘Curiosity’ rover?
A. The lake deposits are around 3.8Ga so have exciting potential because of the lack of tectonic activity and relatively stable temperature environment. It may, therefore, be possible to see on Mars what has long been destroyed on Earth. Plus the aim of bringing some samples back.

Q. Are you expecting to find non-biological signatures or more recognisable organic evidence such as stromatolites?
A. Trace microbial signatures are the most likely or the non-organic products of microbial metabolism which are many times bigger than microbes themselves.

Q. Does any of this matter? What really captures the imagination about Mars?
A. It is part of a core research thrust by NASA, “Are we alone?” and because humans are curious.

The Chairman thanked Max for leading the Society’s first virtual discussion!

John Bennett