

Name: _____

Period: _____

The Origin of Life, continued

Video 1: Origin of Life Video. Bill Martin and Mike Russell (entire video is about 4 minutes)

1. Why is unlikely that life originated at the Earth's surface?
2. What's the difference between "Black Smoker" hydrothermal vents and "off ridge, lost city" vents?
3. Why is the geochemistry of the off ridge vents thought to be conducive to monomer formation?
4. At the vent/ocean interface, sulfur combines with nickel and iron. Why is this important?
5. What is the importance of inorganic mineral compartmentalization?
6. What follows inorganic compartmentalization?
7. In terms of understanding the origin of life, what's the takeaway from this video?

Video 2: The RNA World Hypothesis (from Stated Clearly) (entire video is about 7 minutes long)

1. Summarize the RNA world hypothesis.
2. What is the advantage of RNA over DNA as the first genetic molecule?
3. What's the missing (unproved) step in terms of RNA evolution?
4. What are ribozymes?
5. What would be the "holy grail" in terms of RNA and the origin of life?
6. In terms of understanding the origin of life, what's the takeaway from this video?

Video 3: What is Chemical Evolution (from Stated Clearly). Start at 3:00. Stop at 7:30

1. The key thing to explain is how chemical systems can grow toward _____.
2. Chemical evolution doesn't need _____. Rather it involves _____ production.
3. How can fatty acids form abiotically?
4. What happens when fatty acid concentration increases? Why?
5. How can lipid spheres spontaneously form?
6. In terms of understanding the origin of life, what's the takeaway from this video?

VIDEO NOTES: all videos are on YouTube. Search for...

Origin of Life Video	The RNA World Hypothesis	What is Chemical Evolution
Origin of Life, Russell and Martin	The RNA World Hypothesis, Stated Clearly	What is Chemical Evolution, Stated Clearly. Start at 3:00 minutes.

***The Cradle of Life*, by Nick Lane, *New Scientist*, October 17, 2009**

PETER MITCHELL was the scientist who proposed and proved the idea of chemiosmosis. He established how ATP is produced in chloroplasts and mitochondria as these organelles create proton gradients, then allow protons to diffuse through the ATP synthase channel. This work won him a Nobel Prize in 1978.

“Mitchell’s ideas were about how cells are organized in space, and cellular energy generation is a feature of that,” says geochemist Mike Russell of NASA’s Jet Propulsion Laboratory in Pasadena, California. “The problem is that most ideas on the origin of life lack both spatial organization and a supply of energy to drive replication or growth.”

A few researchers, including Russell, have been rethinking the origin of life in the light of Mitchell’s ideas. They think the most counter-intuitive trait of life is one of the best clues to its origin. As a result, they have come up with a radically different picture of what the earliest life was like and where it evolved. It’s a picture for which there is growing evidence.

According to Mitchell, life is powered not by the kind of chemistry that goes on in a test tube but by a kind of electricity. The energy from food, he said, is used to pump positively charged hydrogen ions, or protons, through a membrane. As protons accumulate on one side, an electrochemical gradient builds up across the membrane. Given the chance, the protons will flow back across, releasing energy that can be harnessed to assemble ATP molecules. In energy terms, the process is analogous to filling a raised tank with buckets of water, then using the water to drive a waterwheel.

Mitchell dubbed his theory **chemiosmosis**, and it is not surprising that biologists found it hard to accept. Why would life generate energy in such a complicated and roundabout way, when simple chemical reactions would suffice? It just didn’t make sense.

It might be counter-intuitive, but chemiosmosis has turned out to be ubiquitous in the living world. Proton power drives not only cell respiration, but photosynthesis too: energy from the sun is converted into a proton gradient in essentially the same way as the energy of food.

And proton gradients are often harnessed directly, rather than being used to make ATP. They drive the rotation of the bacterial flagellum, as well as the active transport of numerous substances in and out of cells. So proton power is central to energy generation, movement and maintaining the internal environment – some of the most basic features of life. This suggests that proton power is no late innovation but evolved early in the history of life, an idea supported by the tree of life. The first branch in the tree is between the two great groups of simple cells, bacteria and archaea. Both of these groups have proton pumps and both generate ATP from proton currents using a similar protein. The obvious explanation is that both inherited this machinery from a common ancestor – the progenitor of all life on Earth.

Think about the properties of that common ancestor, however, says Bill Martin of the University of Düsseldorf in Germany, and you come up with a very strange beast indeed. He starts from the assumption that traits found in both the archaea and bacteria are most likely inherited from the common ancestor of all life (though a few have clearly been acquired later by gene exchange), while traits that are distinct presumably evolved independently. There is no doubt that the common ancestor possessed DNA, RNA and proteins, a universal genetic code, ribosomes (the protein-building factories), ATP and a proton-powered enzyme for making ATP. The detailed mechanisms for reading off DNA and converting genes into proteins were also in place. In short, then, the last common ancestor of all life looks pretty much like a modern cell. Yet the differences are startling. In particular, the detailed mechanics of DNA replication would have been quite different. It looks as if DNA replication evolved independently in bacteria and archaea, according to Eugene Koonin at the National Center for Biotechnology Information in Bethesda, Maryland. Beyond that, many biochemical pathways are catalysed by quite different enzymes. The most surprising and most significant of these is fermentation, the production of energy from food without oxygen. Fermentation, which follows glycolysis, is often assumed to be the primordial method of energy generation. Yet Martin has shown that the enzymes responsible are totally unrelated in archaea and bacteria. It looks as if fermentation evolved twice later on, rather than at the dawn of life.

Baffling boundaries

Even more baffling, says Martin, neither the cell membranes nor the cell walls have any details in common. “At face value, the defining boundaries of cells evolved independently in bacteria and archaea,” he says.

But if that’s the case, what sort of a cell was this common ancestor? A cell with no boundary? Impossible! Something unique? If you exclude the impossible, then whatever you are left with must be true.

If Martin is right, the last common ancestor of life on Earth was a sophisticated entity in terms of its genes and proteins, and was powered by proton currents rather than fermentation. Yet at the same time, its bounding membranes were apparently different to anything found today. It was life, but not as we know it. Then, around 2002, Martin came across the work of Russell. Until that time, Russell had been a lone voice. His geochemical ideas about the origin of life didn’t go down well with the molecular biologists who dominated the field.

From the early 1990s, Russell had been exploring the possibilities of a very particular kind of hydrothermal vent, called an alkaline vent, at the time known only from remnants found in ancient rocks. Unlike the black smokers discovered in 1977, formed by the violent reaction of seawater with volcanic lava rising up at the mid-ocean ridges, Russell’s vents

were much tamer affairs, little more than bubbly rocks riddled with labyrinthine pores.

These vents form when water reacts with the mineral olivine, which is common in the sea floor (and would have been even more common early on, before the Earth's crust thickened). The process produces a new mineral, serpentine, and releases hydrogen, alkaline fluids and heat. It also makes the rocks expand and crack, allowing more water to percolate down, sustaining the reaction. The warm, hydrogen-rich effluent ultimately breaks through the sea floor as an alkaline hydrothermal vent.

Interest in alkaline vents rose in 2000, when Deborah Kelley and her colleagues from the University of Washington in Seattle discovered an active alkaline vent field just off the mid-Atlantic ridge, exactly where Russell said such vents should be. The team dubbed it the Lost City partly for its spectacular spires of rock, which form as carbonates precipitate out in the alkaline fluid.

Like ancient vents, the spires of the Lost City are riddled with tiny pores, some with dimensions not dissimilar to modern cells. And the chemistry fits the bill too. A report last year confirmed the presence of methane and other small hydrocarbons, as well as hydrogen itself (*Science*, vol 319, p 604).

The vents themselves may be much the same as those around 4 billion years ago, but back then the oceans were very different. The primordial oceans were saturated in carbon dioxide, making them acidic, whereas the seas today are slightly alkaline. And there was practically no oxygen. Without oxygen, iron dissolves readily. The vast banded-iron formations around the world reveal just how much iron was once dissolved in oceans – as oxygen levels slowly rose, billions of tons of iron precipitated out as rust.

What this means, says Russell, is that the interface between the alkaline vents and the ancient seas would have been much more conducive to primordial biochemistry than today. In particular, bubbles of iron-sulfur minerals – which have remarkable catalytic properties – would have formed in the pores. Russell has found ancient vents with a similar structure and even reproduced them in the lab.

The fact that alkaline vents would have had a labyrinth of naturally forming micro-compartments is what attracted the attention of Martin. Such compartments could have been the precursors of biological cell walls that he sought, providing a scaffold within which the stuff of cells could form. Together, Martin and Russell have pointed out that identical iron-sulfur minerals can still be found at the heart of proteins that convert carbon dioxide to sugars (using hydrogen gas) in archaea and bacteria such as methanogens and acetogens.

The vent fluid would also have contained nitrogen compounds such as ammonia, and conditions would have favored the production of amino acids – the building blocks of proteins.

That's not all. In the presence of phosphate, minerals might have catalyzed the production of nucleotides – the building blocks of RNA and DNA. And if nucleotides did form by mineral catalysis, the pores in alkaline vents would have had an extraordinary effect.

Simulations by Dieter Braun's team at the Ludwig Maximilian University in Munich, Germany, show that the temperature gradient between the top and bottom of the pores concentrates nucleotides at one end, which encourages the molecules to join together to form strings of RNA and DNA. These larger molecules would then become concentrated to even higher levels. What's more, the convection currents would produce a continual rise and fall in temperature – as used to make DNA in labs across the world.

RNA world

Laboratory experiments by a team led by Nobel prize-winner Jack Szostak of Harvard University, published earlier this year, have confirmed that these conditions do indeed concentrate nucleotides and nucleic acids. The team also found that fatty acids become concentrated, leading to the spontaneous formation of cell-like bubbles inside the pores.

It's hard to imagine a better setting for the RNA world widely thought to bridge the gap between simple organic chemicals and the complexities of DNA and proteins. So the idea that ancient alkaline hydrothermal vents were the incubators for life looks very plausible...

Note: there's a very difficult conclusion to this article that you can find at <http://nick-lane.net/feature-articles/>. Just find *The Cradle of Life*, download and enjoy!