WONDROUS BACTERIA!

Bacterium: *Wikipedia*

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When we think of bacteria, we normally think about getting sick. But the sickness that results is a sign that we are not in harmony with a specific bacteria. In general, we are in great symbiotic harmony with bacteria. In fact, we are completely surrounded and composed of bacteria. Our soils are filled with them. Each acre of soil contains 200-500 pounds of microbes. They thrive in our waters and exist in air. On a personal level, we have 10 times more microbes in our bodies than cells in our bodies and they comprise 10% of our dry body weight. Our digestive system alone has 2-1/2 pounds of bacteria. These bacteria serve us in many ways—they manufacture vitamins for us (B1, B2, B3, B5, B6, B12, and K), they help us with digestion of lactose, help regulate bowel movements, prevent colonization of harmful microbes, manufacture short chained fatty acids, play a significant role in our immune function, have anti-tumor and anti-cancer effects, help protect us from environmental toxins, and promote healthy metabolism. In exchange, we give them a warm, wet place to live and food to munch on. Bacteria are completely indispensable for the well being of every living thing on the planet—plant and animal. If plants and animals became extinct, microbes would surely live on.

Their story is one of wonder and creation of life. The oxygen we breathe is a result of their evolution. They comprise the first “world wide web” and were the first motorized vehicles! They teach us much about communication, competition, cooperation, recycling, and adaptability. They are the initial substance of all life, and without them plants and animals could not survive. This is their story.

Escherichia coli bacteria Wikipedia

In the Beginning

When the earth began, there was no life. A mere 500 million years later were the first microbes, the first life on earth. Fossilized bacteria were found in 1977 by Else Barghoon, a Harvard researcher. He dated bacteria found in South African rock as being 3.4 billion years old. Because they developed while the earth was forming, they developed the ability to adapt quickly and well. Bacteria made the world and atmosphere habitable. For example, early bacteria were anaerobic—lived without oxygen. Many of them produced oxygen as a waste product. As oxygen levels rose, some bacteria began to use this waste product as their source of energy. Aerobic bacteria evolved and kept evolving. Oxygen levels rose from one part per million (.0001%) to a part in 5 (21%). Many microbes died. But some bacteria adapted and learned to thrive in this new environment. We are concerned about pollution and changes to our environment, but this change was far vaster than any acid rain or global warming or other scenario we can imagine. Aerobic bacteria not only learned to exist in a high oxygen environment, they learned to thrive and become dependent on it. This was the real beginning of the biosphere as we know it. As these microbes evolved, they transformed the entire planet.

Paenibacillus vortex colony. 6 cm. in diameter. *Wikimedia Commons*

The bacterial purpose is to survive. In order to do this they have developed refined skills of communication and exchange that allow them to adapt to virtually all situations. They reproduce at amazing rates, dividing as often their food supply permits. Some divide every 2-3 minutes, others every few hours. One bacterium in a million mutates. Most of these mutations are non-viable, but the few that are successful often have beneficial traits that can become dominant over time.

Bacteria didn't have enough DNA to perform all of their metabolic needs, so they began taking what they needed from the environment and eventually became parasites on plants and animals. They "invented" the process of fermentation to generate energy. The fermentation process is the main process of anaerobic bacteria. This process is not entirely efficient and produced wastes. Other microbes would use the waste products of fermentation for energy.

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Fermented Foods

Waste products from one bacterium became the energy source for another. Wastes became a new opportunity for development and change. Bacteria are the ultimate recyclers. Substances such as PCB and oil spills become the impetus for their evolution. There is virtually no substance that they cannot decompose into harmless materials.

Deepwater Horizon oil spill 2006. *Wikipedia Commons*

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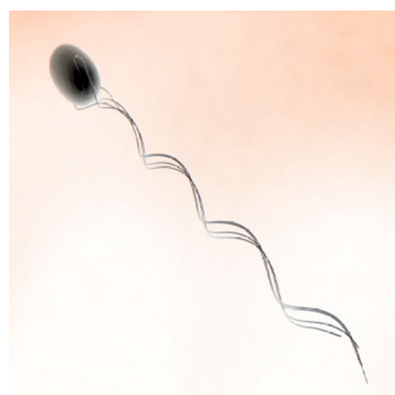
The environment as we know it did not exist. Many transformations occurred. Because there were not set "rules", bacteria continued to creatively evolve. A tremendous variety of type and shape occurred in the bacterial family. They are more diverse than any type of animal. They can live in nearly every environment—independently, inside of animals and plants, in puddles, in the deepest, darkest parts of the ocean, in swamps, in rocks, in the hottest desert, and even in the vacuum of the moon! Astronauts found viable bacteria in a camera that had been in space for three years! Others thrive in salt-water brine! They come in all shapes and sizes-- square and triangular bacteria have even been found! Some are in spirals, called spirochetes, the most well known of which is the syphilis bacteria. Lyme disease is also caused by a spirochete. Some bacteria produce methane gas, others produce oxygen. Some are nitrogen fixers, while others use sulfur for energy. Others respirate iron, manganese, or hydrogen.

They learned to use sugars to generate ATP and to use oxygen for respiration. Other bacteria became "nitrogen fixers". They learned to take nitrogen from the atmosphere and convert it into compound molecules that could be attached to nucleotides and other organic compounds. All organisms depend on this process for usable nitrogen. Still other bacteria developed the ability to synthesize energy directly from sunlight, called photosynthesis. We think of photosynthesis as something that occurs in plants, but it originally began in microbes. Later as the world stores of hydrogen became depleted the first photosynthetic microbes used hydrogen gas or hydrogen sulfide plus sunlight to produce energy. The waste by-product was yellow sulfur pellets, not oxygen! They also learned how to take hydrogen gas and combine it with carbon-dioxide to form CH20. This generated much more ATP (energy) and a huge supply of hydrogen in the form of water. Oxygen was produced as a waste product. Photosynthetic microbes later became incorporated into the plants, living in a symbiotic relationship that we know as chloroplasts and plastids.

Oxygen levels rose dramatically and aerobic bacteria became abundant. They are much more efficient energy producers than anaerobic bacteria. Anaerobic bacteria, via fermentation, can make 2 molecules of ATP for each sugar molecule. Aerobic metabolism can produce up to 36 molecules of ATP from the same molecule. This conferred a great competitive advantage to aerobes. Soon, some developed flagella to move them towards the sunlight and food. They were indeed our first motorized vehicles! This was the beginning of behavior—they moved towards sunlight and food and away from wastes. Over time bacteria spread to all corners of the earth and sea.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There are three types of cells: un-nucleated cells—called eukaryotes (bacteria, virus, fungus), nucleated cells—called prokaryotes, and a newly discovered type called Archea. The differences between these types of cells are more striking than the differences between different types of animals. Eukaryotes, such as bacteria, transformed the atmosphere, were the beginning of fermentation, photosynthesis, oxygen breathing, and removal of nitrogen from the air. Nucleated cells came later. They have greater complexity and can band together to make multi-celled organs and organisms. The organelles inside of nucleated cells were once free-living bacteria. Archea, formerly called archaeabacteria, were discovered in the 1970's and are as different from bacteria as they are from nucleated cells. They are heat loving microbes that can withstand temperatures up to boiling and beyond.

Archaea in Grand Prismatic Spring, Yellowstone National Park
Wikimedia Commons

The Great Bacterial Symbiosis

New research has shown that mitochondria and organelles were originally derived from invading bacteria that ultimately became symbiotic.

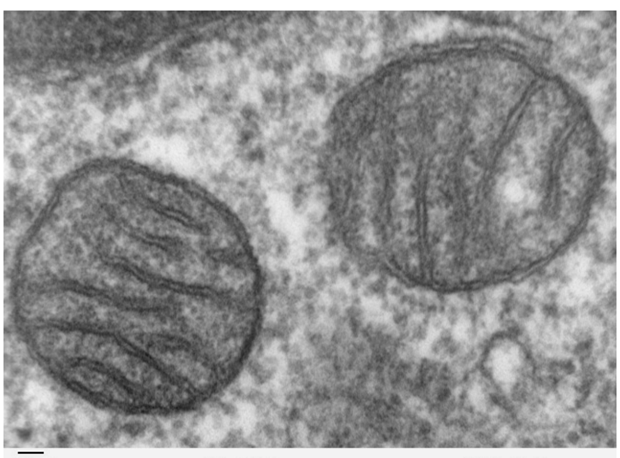
Mitochondria are found in every cell of our bodies, and those of all other animals. Mitochondria are oxygen breathing bacteria that became us. They provide us oxygen and energy in exchange for room and board. It's that simple. Mitochondria occur in all cellular organisms. Because of mitochondria all metabolism of living organisms is remarkably the same.

Mitochondria have so many characteristics common to bacteria that it is now firmly believed that mitochondria were originally invasive aerobic bacteria that eventually learned to live in co-existence with their hosts. This occurred long ago but was first noted by scientists Paul Portier in 1918 and Ivan Wallers in 1925. The DNA found in mitochondria is different from our cellular DNA. In fact mitochondrial DNA is passed to us only from our mother's genes. Their bacterial ancestors waged war with early animals and eventually either the organism died out or learned to cooperate with the bacteria. This process is called "restrained predation" and occurred throughout the evolutionary process. Both bacteria and cell compromised for the greater good. Over time the bacterial component lost some of its RNA and DNA which reduced redundancy within the cellular metabolism. Without mitochondria, nucleated cells cannot utilize oxygen or produce ATP.

There is a new concern arising. Because mitochondria are sensitive to antibiotics, overuse of antibiotics can damage their DNA rendering them functionally handicapped. For example, use of antibiotics is often the trigger for chronic fatigue syndrome. Mitochondrial DNA is three times more easily broken than cellular DNA.

<u>Mitochondria have these traits in common with all bacteria:</u>

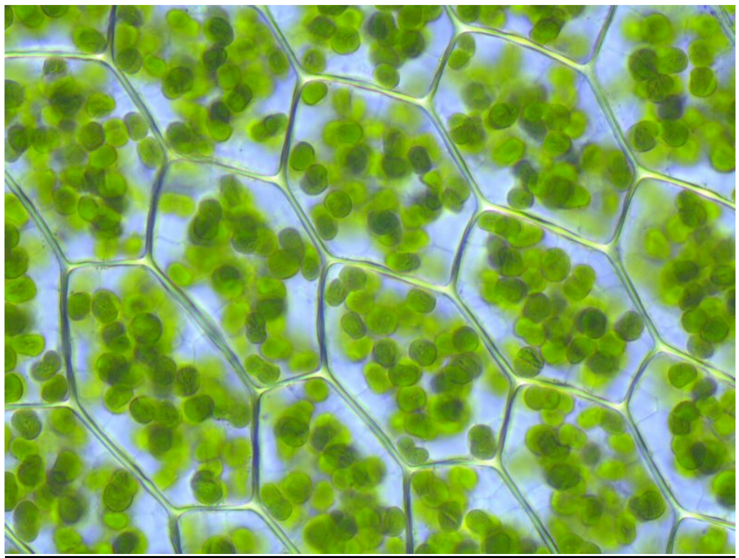
- Have their own DNA
- Divide by pinching and dividing at their own rate, independent of cell division
- Have their own messenger RNA
- Have their own transfer RNA
- Have their own ribosomes
- Their DNA is not bound into chromosomes
- DNA is uncovered by a histone coating, a protein coating
- They assemble protein on ribosomes
- They are sensitive to antibiotics



Mitochondrion
Wikimedia commons

Organelles within cells are also believed to be of bacterial origin. They have DNA that is unlike nuclear DNA but like bacterial DNA. It is believed that at first they were probably dangerous pathogens. Eventually the cells and microbes worked out a peaceful co-existence. The previous pathogens became indispensable to cellular function. Over time redundant functions were lost.

A hundred million years later photosynthesis began to occur. The photosynthetic part of a cell is called a plastid. Plastids can be green, red, blue-green and clear. If the coloring is green, it's called a chloroplast. Plastids are believed to be derived from bacteria called cyanobacteria. When eaten by cells, some of the cyanobacteria resisted digestion with their light trapping pigments still intact. They learned to exist within these cells and a new symbiosis was formed. Plastids resemble contemporary bacteria in ways similar to those of mitochondria. These plastids are now locked in every plant and produce oxygen and supply us with food.



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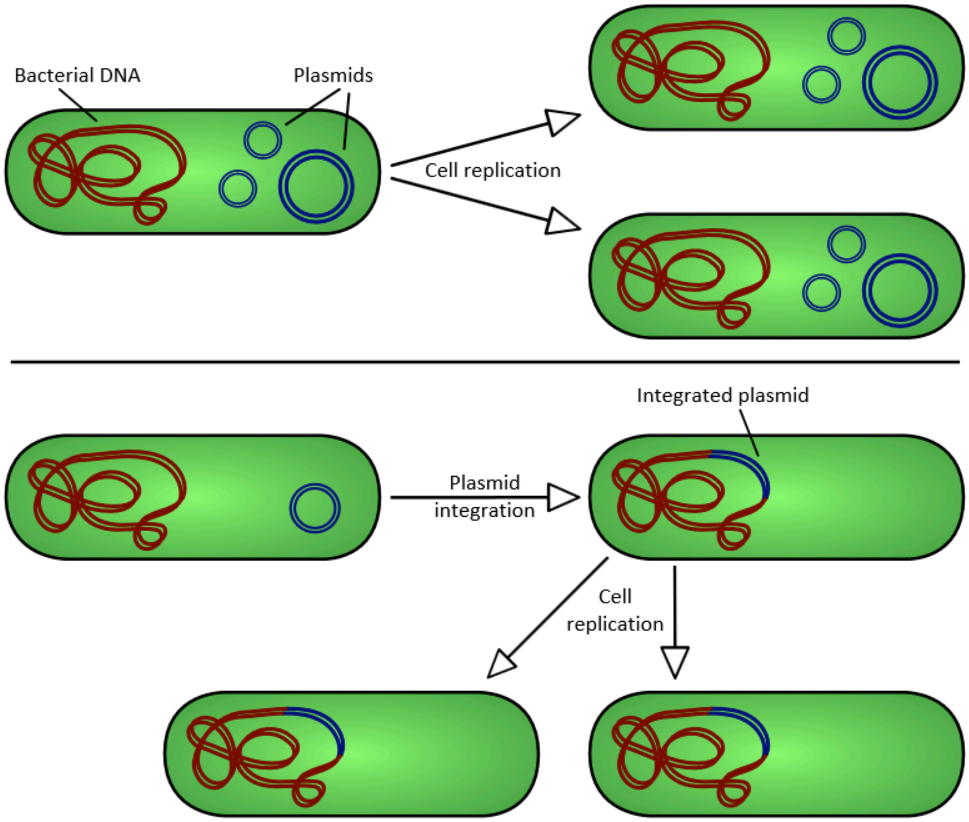
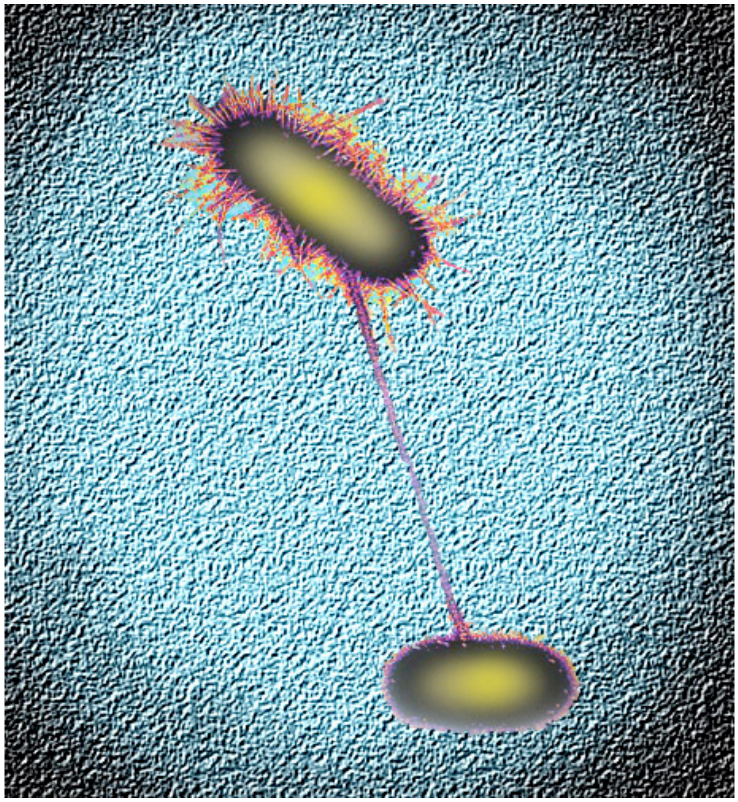
Bacteria: The First World-Wide Web

Each eukaryote bacteria contains a major strand of DNA, which is called a genophore, chromoneme, or large replicon. In addition to this they also have smaller numbers of self-replicating DNA molecules that are visiting from other bacteria, which are called small replicons or plasmids. Plasmids have from 1-25% of the amount of DNA as the larger strands. They are really just little bits of DNA and there are usually 2 or more plasmids "visiting" a bacterium at any point in time. Some of these attach themselves to the large DNA strand and insert themselves permanently, giving new attributes to the bacteria. Other plasmids circulate inside the bacteria or attach to the membrane, directing functions. If the microbe finds the information useful, plasmids can jump over to the DNA strand and become permanently incorporated. There are also non-replicating fragments of DNA that can enter a cell if it has the appropriate receptor. They will enter the cell and replace a similar fragment on the large DNA replicon strand. Some of these replicons can insert themselves on any size replicon—small or large—and are called tranposons. In this way bacteria can copy up to 90% of their genes from another microbe.



Plasmid Replication *Wikimedia Commons*

Eukaroytes have up to 300 times less DNA than in a nucleated cell, this transfer of information allows them to compensate—either borrowing or permanently gaining new skills and information (like borrowing a book or video from the library or actually buying it). This is the way bacteria trade information which can allow them to become resistant to antibiotics. And the truly amazing thing is that different varieties of bacteria can trade information across strains and even to entirely different types of bacteria. This is truly just like the world wide web. Because of this trait, all of the world's microbes are essentially one genetic pool. They are essentially one clone, composed of highly differentiated cells! They completely share all information and know-how. Because of this rapid rate of transfer and because of their quick reproductive rate, they can evolve very quickly—often in a matter of days or hours. They can accomplish what would take us millions of years, in a matter of just a few years.



Bacterial conjugation www.microbiologybytes.com/

More specifically, replicons/plasmids transfer information via different pathways: conjugation, transformation, and transduction. Conjugation is when different strains or types of bacteria exchange information. This occurs through little tubes, called pila. The donor transfers a copy of the genetic material to the tube to the recipient. The transformation process is when a bacteria absorbs DNA from its surroundings without destroying or harming the parent bacteria. In this transfer the absorbing bacteria gains new information and the parent bacteria is left unchanged. In transduction, a bacteriophage (type of small replicon) lives peacefully inside a bacteria. If exposed to an environmental change, like light or heat, they can begin to replicate and infect the host bacteria, passing traits of previous hosts onto it and significantly changing its characteristics. It is primarily through transduction and conjugation that antibiotic resistance occurs. Some plasmids can encode information for two or three antibiotics simultaneously. Like us, bacteria use these tools to exchange information, and like us they don't carry all of the tools they need around all of the time! The information that is acquired is passed on from neighbor to neighbor and from generation to generation.

Bacteria and the Modern World

In recent history we use bacteria for many products. They are used to clean up oil spills and pesticide wastes. They can degrade even our most persistent toxins like PCB's. We use them to manufacture drugs, such as insulin, and to manufacture vitamins, amino acids, and antibiotics. They are used in fermentation processes. We use them to bake bread! They help us to more easily extract minerals from mines. Scientists now have such understanding of bacteria and plasmids that they can insert specific plasmids into bacteria to promote a new characteristic.

Over use of antibiotics has encouraged bacteria to develop resistance. It is believed that the agricultural industry, which uses the majority of antibiotics, is in large part responsible for this resistance. 90% of antibiotics used in animal husbandry are used either as prophylactics or as growth promoters. They are used in low levels that allow for bacterial transformation. Overuse of antibiotics may also contribute to mitochondrial diseases, which we are seeing more and more of.

In Conclusion

It seems that we have much to learn from our bacterial friends. They have learned that killing an enemy is counter-productive. They have learned that cooperation and communication can a strong world. They recycle everything. They adapt whenever crisis arises. They don't whine and cry, they just adapt! They are self-regenerating and self-regulating. On a small scale they represent the entirety of systems theory. They prove that you don't have to be big to make a difference, you just have to be persistent, flexible, and patient.

With the current knowledge of our symbiotic relationship with bacteria, it seems useful to change the current philosophy of killing them. Instead, we need to develop new ways to encourage them to work in cooperation with us, rather than in competition. When we can restore the appropriate microbial communities, health occurs personally, locally, and globally.

Bibliography (Written at a time when you sat in libraries to do research!)

- De Kruif, P. H. (1926). Microbe Hunters. New York, Harcourt, Brace & World.
- Dixon, B. (1994). Power Unseen, How Microbes Rule the World. New York, W. H. Freeman & Co. Ltd.
- Ewald, P. (1994). Evolution of Infectious Disease. New York, Oxford University Press.
- Garrett, L. (1994). The Coming Plague, Newly Emerging Diseases in a World out of Balance. New York, Farrar, Straus and Giroux.
- Gould, S. J. (1989). Wonderful Life, W. W. Norton.
- Khachatourians, G. (1998). "Agricultural use of antibiotics and the evolution and transfer of antibiotic-resistant bacteria." Canadian Medical Association Journal(159): 1129-36.
- Lipski, E. (1996). Digestive Wellness. New Canaan, CT, Keats.
- Margulis, L. Dorion, S. (1986). Microcosmos, Four Billion Years of Evolution from Our Microbial Ancestors. New York, Touchstone, Simon & Schuster.
- McGreer, A. (1998). "Agricultural antibiotics and resistance in human pathogens: Villain or scapegoat?" Canadian Medical Association Journal(159): 1119-20.
- Watanabe, M. (1994). "Hot-Vent Microbes: Looking backward in evolution for future uses." The Scientist **8**(11): 14-16.