5.0

THE ORIGIN OF LIFE.

0:00–0:27

THE ORIGIN OF LIFE

Hi, I'm John Green, and welcome to Crash Course Big History where today, we're going to get a life. Or at least, the Earth is going to get a life.

But first, today we have to start with a disclaimer. The origin of life is in many ways a blank spot in the pages of history. Like the mystery surrounding the Big Bang or dark matter, the origin of life is still pretty puzzling to us. Like, thanks to scientific research, we have a general idea of what needed to happen to bring about life, but we're pretty fuzzy on the details.

0:28–1:14

COLLECTING EVIDENCE TO REFINE THEORIES

Mr. Green, Mr. Green! I mean, if we don't know, then why are we studying it as history? Maybe we should just, like, let scientists figure all that stuff out and then they'll get back to us, like, after this class is over.

Well, me from the past, I'm sure the thousands of scientists working on that question appreciate your patience, but even when we have blank pages in the annals of history, it's still history. Like, there are still competing ideas and theories about the presidency of Franklin Delano Roosevelt, but the fact that there are open questions doesn't mean it didn't happen. Sometimes we don't have a clear narrative of events and it's up to us to collect more evidence and refine those theories, but first, we have to know about the current evidence and the current theories. I mean, ultimately, that's what history is.

1:15–1:37

LIFE EMERGES

I'm Hank Green. And this is still Crash Course Big History. Last time, we left off with a newly born Earth that was molten hot, pelted by asteroids. Then, millions of years of torrential rainfall cooled the surface and created the first oceans.

We know that life emerged in the oceans between 3.5 billion and four billion years ago. We have solid fossil evidence for life 3.5 billion years ago and many scientists are pretty confident that life was around 3.8 billion years ago.

1:38–2:04

WHAT IS LIFE?

It's pretty clear that life is a different thing from the rest of the Universe, but what makes up that difference? I'm kind of surprised that this turns out to be a super puzzling question that we have yet to come up with a 100% satisfying answer to. But some of the major characteristics of most life are, it adapts to the environment, it has a metabolism that processes energy to keep itself going — like humans do with pizza — and it reproduces, whether it be a cell splitting in two or two animals…doing their thing in nature.

2:05–3:09

EXCEPTIONS TO THE RULE

Even these simple criteria have their problems, though. Some animals, like mules are born unable to have offspring. Some microorganisms can shut down their metabolisms for long stretches of time, but neither are exactly dead or not life. Given the incredible variety of species, definitions for life are, by necessity, very broad, but one such definition by big historian Fred Spier is, and I quote, "A regime that contains a hereditary program for defining and directing molecular mechanisms that actively extract matter and energy from the environment with the aid of which matter and energy are converted into building blocks for its own maintenance and, if possible, reproduction."

In other words, what makes you different from the stars that, while a stars burns down till it dies and doesn't actively float around the cosmos looking for more fuel, a living organism does actively seek out pizza to keep itself going, preferably long enough to, you know, have some babies. But how do we know what we know? How do we know that life is just a different kind of molecular mechanism and not something more profound? Well, we can test these claims, and we do, using science.

3:10–3:35

LIFE AND NON-LIFE

Because life looks so radically different from the inanimate Universe, people once thought that life was made of completely different stuff.

Then, in 1828, a German chemist, Friedrich Wohler, used inorganic chemicals to synthesize an organic chemical. This was a big deal just as Newton's theory of gravity showed that the heavens and Earth followed the same physical laws, Wohler's experiment proved that life and non-life follow the same chemical laws, which implied that life could emerge from non-life.

3:36–4:09

SPONTANEOUS GENERATION

Even this idea wasn't completely new. For centuries, the Aristotelian idea that life just spontaneously emerged from non-life was widely believed. For example, if you put some rotten meat out in the sun, eventually the meat would transform itself into maggots. You could probably work out the weaknesses in this theory.

17th century scientists took meat and various other objects thought to spontaneously generate life, boiled them to kill off any eggs previously laid by insects, sealed them in jars and nothing happened. Oh Aristotle, first you told us that snot was our brain coming out of our noses, and now you made all those nice people waste their steak dinner.

4:10–4:56

CLAIM TESTING

This however did not rule out some form of life force in the air. Some invisible force in the earth's atmosphere that could enter an object and literally breathe life into it.

But spores from plants can also travel in the air, as can microorganisms. So in the mid-19th century, Louis Pasteur boiled some organic broth friendly to life and placed it in a flask with a swan neck to trap plant spores and smaller particles. If a life force was in the air, it could enter freely while spores and other particles would get trapped in the U-bend. And what happened? Nothing. A century and a half later those flasks are still devoid of life. The conclusion: The ancients were wrong. After a dose of claim testing, it became clear that life must emerge from the inanimate world by chemical processes that are discoverable by science.

4:57–5:49

SINGLE-CELL ORGANISMS

But what did early life look like? Well, for a whopping 2.1 billion of the 3.8 billion years of the evolutionary epic history was made by tiny, single-cell organisms called prokaryotes. That's roughly 55% of the entire story of life. Now some of those prokaryotes evolved about 1.7 billion years ago into slightly bigger single-celled organisms called eukaryotes. And then, you know, that kept happening and eventually us. But for now, let's just talk about prokaryotes.

Prokaryotes lived in the seas and ate chemicals in their surrounding environment. Now these microscopic prokaryotes might not sound very impressive, but they do make up the vast majority of your family tree. They're also distant relatives of the modern bacteria that are everywhere. Crawling around the room that you're in right now, crawling all over you, crawling inside of your intestines. That's right, somewhere right now there's a bacterium that will give you food poisoning in an undercooked hamburger, and it is your cousin.

5:50–6:17

COMPLEXITY

But the thing is, even in its earliest stages, single cell life was massively complex compared to the inanimate Universe. I mean I know these are tiny little specks, but compared to everything else that had happened on earth until them they were an immense tangle of chemical networks and building blocks.

But how did an object as ridiculously complex as a prokaryote first emerge? Well, first of all, it's very difficult to think of how life would form in an oxygen-rich atmosphere like present-day Earth's.

6:18–7:08

OXYGEN IS CREATED

Oxygen is kind of a nasty, highly reactive chemical. In fact, if the oxygen levels in this room were substantially higher and I would just rub my hands together really fast, I could burst into flames. And while that would make for a nice viral YouTube video, I would rather not be on fire than get lots of views.

3.8 billion years ago, the free oxygen content of the atmosphere was at negligible levels, which had some not so pleasant consequences. For millions upon millions upon millions of years, life dwelled fairly deeply in the ocean, eating chemicals and staying where the earth's heat kept warm. Eventually, some prokaryotes floated near to the top of the ocean and started using sunlight, water, and the carbon dioxide that was abundant in the earth's atmosphere to sustain their own complexity using this sweet chemical process they'd come up with called photosynthesis.

The waste product of this chemical process is oxygen. And these photosynthesizing prokaryotes pumped a lot of it into the atmosphere.

7:09–7:46

OXYGEN HOLOCAUST

By around 2.5 billions year ago, the amount of free oxygen in the atmosphere was up to about 3%. Oxygen can be nasty and so scores and scores of tiny single-celled organisms couldn't handle it and died off in a massive wave sometimes known as the oxygen holocaust. So many species of single-celled organisms, each with the potential to evolve into more complex life were wiped out. Even at this early stage, our evolutionary ancestors were squeezed through a bottleneck. And this will not be the last such disaster that nearly wiped everything out. Next time you have a bad day remember that it is amazing that you are alive at all, much less a member of a self-aware species living at the height of human technological progress.

7:47–8:04

EUKARYOTES

Speaking of ancestors, somewhere between 1.6 and two billion years ago, the eukaryotes evolved. And because you, your dog and the chicken you ate last week and the mushroom you ate the week before all descended from them, they really put the "you" in eukaryotes. And eukaryotes contained organelles like cellular organs that enhanced their abilities.

8:05–8:49

SEX ENHANCES EVOLUTION

About 1.5 billion years ago, eukaryotes invented sex. Up until that point, single-celled organisms split in two or cloned with no need to find a partner for romance and DNA exchange. Sexually reproducing eukaryotes possibly obtained these abilities through cannibalism, just eating each other, which may have led to some accidental exchange of DNA.

After that, the evolutionary advantages of sex probably resulted in it catching on. Having a partner means having two sets of genes and thus a wider range of genetic diversity from which evolution can pick and choose. Sex is a huge deal. It enhanced evolution, and therefore deserves to be classed as one of the most revolutionary advances in the history of life on earth. And a huge leap forward in the rise of complexities since the very beginning of the Universe.

8:50–9:25

FROM WHERE DID LIFE EVOLVE?

So where did these complex single-celled organisms come from in the first place? Well, Charles Darwin's own hypothesis was that life evolved in some "warm little pond suitable for fostering life." Other scientists postulate that life may have formed from organic chemicals next to the warmth of underwater volcanoes. And still others champion the idea of panspermia, which states that life may have evolved elsewhere in the Solar System and then been transported here by an asteroid, which seeded the earth.

Like I said, this is a blank spot where many different historical theories are seeking evidence to clarify what happened. It's possible actually that this problem could be solved in our lifetime, which is pretty exciting.

9:26–10:10

LIVING CELLS REPLICATE

Anyway, whatever physical forces were at play, primitive organic chemicals eventually came together into balls with protective membranes. They would have reproduced and proliferated much as life does today, but the earliest blobs or organic chemicals would have reproduced clumsily, inaccurately with many useful adaptations getting lost. Essentially, these molecular mechanisms were badly programmed.

In 1950s, James Watson, Francis Crick, Maurice Wilkins, and Rosalind Franklin discovered how living cells replicate using DNA or deoxyribonucleic acid.

DNA is a double-stranded molecule that contains a list of orders for how it wants a living cell to be constructed. And then a single strand, RNA, reads those program orders and sets in motion the production of the proteins necessary to accomplish them.

10:11–10:51

ALL LIFE HAS DNA

All life on earth has DNA, which is one of the reasons we know that all living things on earth — from farmers to fish, from moles to microbes — have a common ancestor. It's why you share 98.4% of your DNA with a chimpanzee, and why you share nearly half of your DNA with the banana that it likes to eat. Not quite cannibalism, but we do eat a lot of our distant cousins.

But where do DNA and RNA come from? Another mystery. How could such complex programming evolve from simpler organic forms?

One leading contender is the RNA world hypothesis, which postulates that there might have been an earlier version of just RNA, which was capable of both coding and self-replicating and out of which separate and more complex structures evolved... DNA.

10:52–11:11

DNA AND RNA COMPLEXITY

DNA and RNA operate in extremely complex ways themselves, which is what you'd expect with something with as many connections and varied building blocks as life. By the way, we're not expecting you to come away from this video with a complete understanding of how DNA works. There is a link in the description to our Crash Course biology video on DNA though if you want this mind-blogging concept to come down a few boggles on the boggle scale.

11:12–11:38

HOW AND WHY THINGS WORK

Remember this as well: when looking at a historical narrative, it's always useful to know how things work. But it's still more useful to know why they work. Because they can influence the future sequence of events. Like you don't have to know exactly how to design, build, assemble, and fire a 15th century long bow to understand the French and English conflict in the 100 Years' War. All you need to know is that long bows made things pretty unpleasant for a lot of French people. Like, "There's a piece of wood sticking out of me" unpleasant.

11:39–12:17

DNA REPLICATION

DNA replication is an amazing, flabbergasting process that allows life to copy itself and sustain its own complexity. It copies a living organism with stunning precision. But even this impeccable copying process can occasionally be somewhat peccable. Once every billion copies or so there is an error. These errors result in a slight mutation. These can have no effect, they could be very good, or they could be very bad.

If useful, it allows an organism to be more successful and likely to pass on its genes. If not so useful, things go poorly and the gene does not get passed on. On the scale of millions of years, these copying errors are the engine of evolution and the origin of new species.

12:18–12:57

RESHAPING ORGANIC MATERIAL

They allow the tiny layer of fragile organic material sitting atop the hulking geological structures of the Earth to be shaped and reshaped like Play-Doh from prokaryotes, to eukaryotes, to trilobites, to dinosaurs, to Abraham Lincoln.

As Charles Darwin put it at the end of *The Origin of Species*, "There is a grandeur in this view of life, with its several powers having been originally breathed into a few forms or into one. And that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning, endless forms most beautiful and most wonderful have been and are being evolved."

More on that next time.