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Once You Get Started

A brief and somewhat personal introduction to some recent developments in the theory of evolution

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FROM THE SCIENTIFIC point of view, life on this planet began as a result of physics and chemistry. It had to. It must have been made from the matter that happened to be available, here on this planet, all those billions of years ago. It must have arisen as a consequence of the physical and chemical properties of this matter, without the intervention of any kind of magic.

It's true that this particular "consequence" of physics and chemistry seems unlikely, to say the least. Physics and chemistry created *life*, you say? All these living things, spreading all over the Earth, some of them eventually becoming—the *least* likely of all chemical reactions, one would think—human beings?

Well, no one is proposing that human beings walked out of the "primordial soup." (No-one but the creationists, that is.) However unlikely it may be, life did get started somehow, because here it is, and here we are. Presumably, it started very simply and got progressively more complicated. That sounds obvious and rather broad, but careful consideration of this proposition has led to some beautiful insights.

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Certainly, life cannot arise just anywhere. You have to have special conditions. You probably want to be on a rocky planet rather than a gaseous one, pretty close to a star so

there's lots of energy, but not too close or all the water boils off—don't you hate it when that happens? Such a place is not easy to find. Setting out from the Sol system looking for a suitable planet, you could travel thousands of light-years in every direction without knowing for sure that you were going to find a place to land where you could relax, take your boots off, and breathe the air. Miraculously, the third planet from Sol is just about perfect.

Of course, it's not exactly a coincidence that we find ourselves here. First, evolution has been adapting us to this blue planet and its small yellow sun for billions of years, so by now we find it quite lovely. Only, it's we are adjusted to it, rather than the reverse. Another, interesting angle on the "coincidence" is called the anthropic principle. Were this planet not suitable for intelligent life, we would not be here living on it. So it's only on those (perhaps extremely rare) planets capable of producing thinking beings, that thinking beings appear, and look around and wonder how they got so lucky.

Some scientists apply this consideration not only to the planet Earth but also to the universe as a whole. Cosmologists note that if things had been put together just a tiny bit differently at the beginning, we would have ended up with a completely different universe. Make the force of gravity just a tiny bit weaker, for example, and you get a universe that thins out so quickly after the Big Bang that stars and planets never form. A tiny bit stronger, and the whole thing quickly collapses back in on itself. Either way, you never get anything that's alive. What incredible luck, then, that the universe turned out just right! Or, some people have asked, doesn't this prove the intervention of a deity? No. Quite simply, if the universe hadn't produced any people, then we wouldn't be here speculating about why it has people in it.

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The reason it's "good" to be on a rocky planet is that rocks are made of some very special materials, things you can't get just anywhere—things like iron, silicon, carbon, and oxygen. In case you haven't heard about it, I want to mention the astonishing origin of these special substances.

The Big Bang created a universe made almost entirely of hydrogen. There was *nothing else in the universe* but some wisps of hydrogen, a little helium, and a whole lot of empty space. Many things are not known about the early universe, but this is well established. Now, as far as we know, you can't make an organism out of hydrogen gas, so there was probably no life in the universe for the first billion years or so. There was plenty of activity, however. The very first stars were forming, eventually creating entire galaxies from the hydrogen mist.

Recall that hydrogen is the simplest atom, with just one proton in the middle. Helium has two protons and two neutrons. The process of nuclear fusion inside stars "fuses" lighter atoms to make heavier ones. Four hydrogens can be turned into one helium, with a little mass left over that gets converted into a lot of energy. That's what makes stars shine. (It's actually much more complicated than that, but we'll gloss over the details because I don't understand them.) As they grew and changed, the early stars, made of almost pure hydrogen (element #1), "cooked up" a lot more helium (element#2), plus some new elements that had never existed before, like beryllium, carbon, oxygen, and neon (elements 4, 6, 8 and 10, respectively).

Many stars, when they have run out of fuel, explode with awesome force instead of just quietly burning out. This is called a *supernova*. Some of the first-generation stars would have eventually exploded, spreading their new creations through the vast interstellar spaces. Still, it doesn't seem likely that any living beings could have been made out of the

first six elements. But some of this material would eventually find its way into new stars and be “cooked” some more, perhaps to be released again into space by another supernova. Gradually, over billions of years, heavier elements like potassium and iron and zinc (elements 19, 26, and 30) accumulated in the interstellar medium. Only after several generations of the birth and violent death of stars could there be enough of these heavier substances that, as new stars continued to form, rocky planets might form along with them. Only then, could life evolve.

In other words, it has been reliably established, just in the last few decades, that most of the elements necessary for life—most of the matter in our bodies—originated inside the bodies of stars.

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Let us return to our main theme: the crazy things that can happen on a little planet made of star-stuff.

Life, considered as a natural consequence of the physical properties of the materials available on rocky planets, may in fact be highly unlikely. Many scientists working on the problem of life suspect that even very simple life forms such as algae and bacteria are exceedingly rare across planetary systems in general (though there are plenty of dissenters on this particular point). If inhabited planets are indeed few and far between, and if even those few are unlikely to harbor anything more intelligent than a paramecium, this would certainly help to explain why, as far as we know, none of their inhabitants has yet visited us.

On the other hand, there is a strong consensus among scientists today that given certain conditions, the appearance of life is inevitable.

It must have started very simply, right? Clearly, you can't just take raw ingredients and mix them together and get a bacterium, to say nothing of a redwood or an ostrich. Where could the starting point have been? What might be the *simplest possible* form of life?

Since there's no record from those early days, we have to approach it logically rather than archeologically. Thinkers like Dennett and Dawkins (see references at the end) propose the following. Suppose that under certain conditions, certain molecules, of a kind that were plentiful on the early Earth, can accidentally clump into compounds with the property of reproduction. I don't mean sex. It's not nearly that complicated. It's more that these new compounds are like tiny molecular factories, which automatically, without anything you could possibly call thought, feeling, or intention, make copies of themselves.

Could such a thing really happen by *accident*? The necessary parameters and conditions, and the resulting probability of success, are objects of intense study as I write this. The consensus so far seems to be that, at the very least, it's not impossible.

After the Earth had cooled off from the heat of its formation, it's estimated that *300,000,000 years* went by without this strange event taking place. Perhaps this is a measure of just how unlikely it was. Nevertheless, eventually, something like this did happen—unless life migrated here from another planet, which is not inconceivable. In that case, it would have happened *there*.

So. Somewhere, long, long ago, a few carbon-based molecules happened to clump together in such a way as to create a compound that started making copies of itself. Not because it "wanted to" or anything. It just happened to have that property. The exact mechanism is unknown, but it doesn't matter to our story. Somehow, the new compound absorbed materials and energy from its immediate vicinity, and created more compounds just like itself. This chance event was the beginning of life (though it would still be a long, long time before there was anything around that one would think of as "alive").

Given this one assumption—our "little molecular factories"—the emergence of life, and the future evolutionary diversification of that life, become inevitable rather than improbable.

Three simple logical steps lead to this outlandish claim. It's a bit like a mathematical theorem—not as airtight as a real theorem, but pretty compelling nevertheless. Let's call it a recipe so we don't make the mathematicians furious. Follow along and see if you agree, it makes a heck of a soup.

The first proposition, I mean *ingredient*, is almost too obvious to mention: if you have a little factory, and what it makes is more little factories, and you turn it loose, sooner or later you're going to have a lot more little factories than you ever wanted.

Secondly, add a pinch of the following. It stands to reason that occasionally, for whatever cause, one of these little factories will make a new factory that is not exactly like itself. Now in general, a "mistake" of this kind will be a dud. Built wrongly somehow, it won't "know how" to make more factories. It won't reproduce as the original one did. Instead, dissolving back into its constituent molecules, it vanishes from the world and from our story. However, once in a blue moon there could plausibly be a mistake that still works as a factory: a self-replicating compound of a new kind.

Some of these "interesting mistakes" will reproduce more quickly (compared to their "parent"), others more slowly; some will be larger, others smaller; some will tend to survive longer before breaking up, others not as long; and so on. Again, the details are not important; the point is that *new kinds* of molecular factories can appear. And each new interesting mistake, each new variation on the theme of the molecular factory, will (by definition) start making more factories—*not*, please note, copies of the factory that made the mistake. These are *copies of the mistake.*

Let's go through that again. We began by imagining that some sort of compound having the property of self-reproduction can be formed accidentally. Presumably, there are other, similar compounds that also have this property. If the original factory can be slightly modified, and if the modified version makes *copies of itself*, rather than copies of the original one, we will now have two kinds of factory coexisting in the environment. Given enough time, and we have billions of years to play with here, we can suppose that if this development *ever can* happen, it *probably will* happen. In that case, there will eventually be a whole *variety* of different kinds of little molecular factories, each one busily constructing more factories exactly like itself... except for the occasional mistake.

Here's the third and last ingredient in our *Gedankensuppe*. The presence of all these factories churning away changes the environment they happen to be churning away in. Each factory has to absorb certain materials from its environment to be able to make more factories, so those materials will tend to get used up. It may also happen that the factory-building process creates certain materials as "unwanted" by-products. These waste materials will accumulate in the immediate environment. The interesting thing is, the different kinds of factories will use up different building blocks, and cast off different wastes. So as the environment changes, with some materials becoming scarce and others becoming plentiful, the odds will tend to shift as to *which kinds* of factories are going to continue to be able to make *more factories of that kind*.

Here—be careful, it's hot... Good soup, no? I call it: evolution.

To make evolution you need only three conditions:

1. Factories making more factories just like themselves. (In the scientific literature, this is called *heredity*.)
2. "Mistakes" in copying, leading to new types of factories (*variation*).

3. Limited resources, leading to different rates of production for different types of factory (*selection*).

I've changed my mind. It really is a lot like a theorem. Seen this way, evolution looks a lot less like a recipe, or even a *theory*, than it does like a mathematical law.

Here's an example, for comparison, of another mathematical law. For any triangle on a flat surface, if two of the sides meet at a right angle, the squares of the lengths of those two sides add up to the square of the length of the third side. A mathematical truth is different from a natural truth. "When you let go of something, it's pulled toward the center of the nearest planet" is a natural truth: an *observed* fact, rather than a *mathematical* fact. (We can use math to *solve problems* in gravitation, but that's something else.) A mathematical law is absolutely guaranteed; the conclusion follows inevitably from the premises, given certain standards of logical inference. Darwin's law turns out to be mathematical, like Pythagoras's—not physical, like Newton's.

Richard Dawkins refers to this new understanding as Universal Darwinism, because it implies that life, *wherever* it might be found in the universe, from whatever materials it might be made, *must* evolve in a Darwinian fashion. Anything that reproduces, as long as its process of reproduction has the characteristics of heredity, variation, and selection, *will evolve*.

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This article is, in part, a response to the disingenuous "thinkers" who insist that the currently hypothesized mechanisms of the origin of life cannot possibly be true, and who manage somehow to construe evolution's "failure" as a support for their personal interpretations of Christian scripture. This argument makes no sense. The thing is, even if *all* the current scientific theories were somehow to be proven wrong, that wouldn't mean biblical fundamentalism is correct. Fundamentalism is already known to be wrong.

Therefore, if all the current theories failed, it would mean, quite simply, that *we don't know* how life originated—and science, not belief, would still be the way to find out.

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Unlike the Pythagorean theorem, the law of evolution has had astonishing consequences in our corner of the natural world. Three billion years on, there are innumerable "factories" of (literally) innumerable different types. The Earth is practically covered with them. Life has altered the very character of the planet.

A radically new kind of factory has evolved here in the last billion years or so. Instead of living alone, these factories form what might be called "industrial cooperatives": they build huge, elaborate, mobile, armored colonies to live in. A trillion factories live and work in each colony, where they are somewhat protected from the environment. The price paid for this protection is that the factories can interact with their environment only indirectly, by remote control so to speak, through the agency of the colony as a whole. And get this. Very recently, colonies have evolved that drive cars, and take rocket ships to the Moon, and worship gods, and write books! It's nuts!

I am one of those colonies, though, so I'm glad this has all happened.

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Many people find this view of the origins of life, and the origins of people, profoundly disquieting. Personally, I find it exhilarating.

One day I was walking up Broadway in lower Manhattan and I saw that tufts of grass were living in the cracks in the sidewalk—growing up through the concrete, through the noise, through the diesel fumes and the heedless tread of pedestrians. I thought: Life doesn't care! It grows, not just where it's *easy* to grow, but everywhere it can *conceivably* grow. And in that moment I was happy.

Evolution is the basis of life on this planet, and anywhere else life may exist. It *has* to be—and because of the mathematical inevitability of the law it's based on, life itself is a powerful force of nature—perhaps the *most* powerful force in nature.

Life is like fire. However unlikely it may be to get started, once it starts it keeps burning until its fuel is exhausted. Life is much more powerful than fire, though, because if its fuel starts to run out it will almost certainly figure out how to use some other kind of fuel. I don't mean people figuring it out with their brains, though that can happen too. I mean that life itself is inherently adaptive. It doesn't want anything. It isn't trying to do anything. Nevertheless, it is capable of adapting to almost any conceivable change in its environment, and continuing to thrive. It renews itself—automatically, continuously, and implacably. Once it gets going, it's all but unstoppable. Living beings have been evolving on this planet for well over three billion years. Given the first, the slightest opportunity, *some* of them will leap out from this planet to other planets, and then to other star systems. There are a trillion worlds to choose from out there, even if they're very far apart. It's just a matter of time, really, before life spreads throughout the galaxy. It doesn't *want* to. It just *will*.

In its extravagant fecundity, its bone-chilling ruthlessness, and its power to reshape entire worlds, the "highly unlikely" phenomenon of life is perhaps more amazing than any deity ever conceived by human beings. Every second of every day, uncountable trillions of living beings are borning, and living, and dying—and that's just on this one planet. Life does not care which ones survive and which vanish. It just keeps making more, and it will never stop until that's absolutely impossible. It's hard to imagine that ever happening, isn't it? But even then... I don't know, there's something interesting here. If life ever becomes impossible... even then, it won't *want* anything, do you know what I mean? It won't *mind*. It will simply stop, just the way it started: with no plans, and no regrets.

FOR FURTHER READING

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