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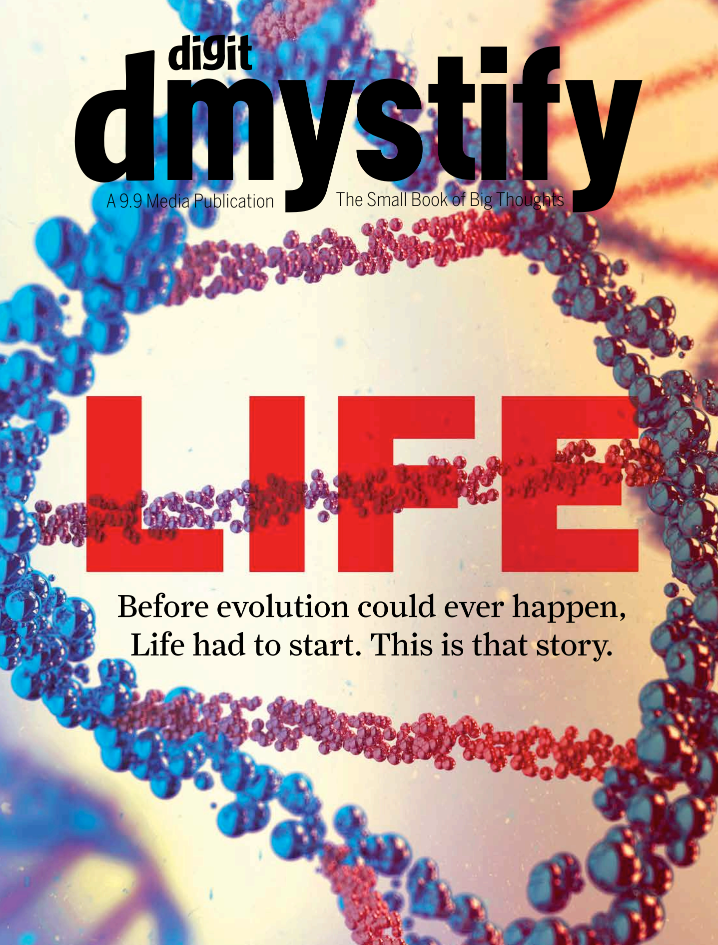
The Small Book of Big Thoughts



LIFE

Before evolution could ever happen, Life had to start. This is that story.

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JULY 2016

Origins

Where did we all come from four or so billion years ago

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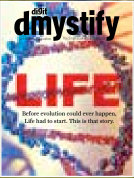
INSIDE



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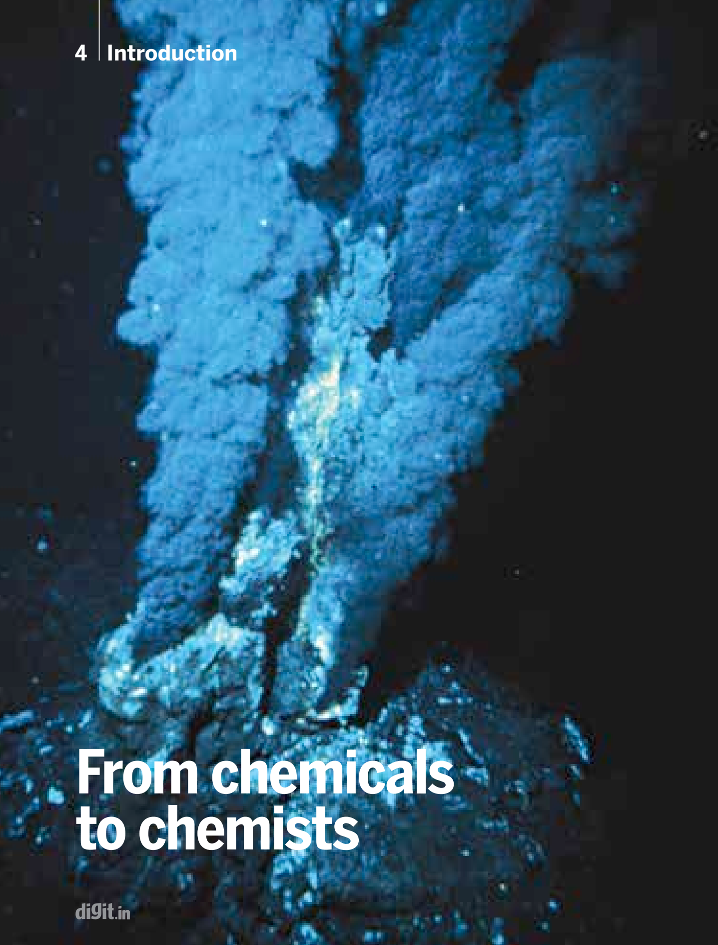


From chemicals to chemists

This book will aim to answer the questions that people have about how life got started on planet Earth. While many mistakenly believe that Darwin's theory of evolution answers the question of how life began, nothing is further from the truth. Evolutionary biologists may be looking for that answer, but the theory of evolution itself doesn't at all care how life got started, it only looks at how life kept on gaining complexity and evolving into the billions of species and life forms that we have seen in our past via the fossil records.

The term "evolution", however, is often used to describe even chemical reactions – especially chemical reactions that are studied when trying to understand how life got started.

However, we believe that expecting Darwin's theory of evolution to answer the question of how life began is like expecting the second law of thermodynamics to explain how teeth decay – or use entropy to explain why this writer has a toothache as he writes this. There's probably some relation, but it's not like the second law of thermodynamics was written with this darn tooth in mind...

We digress, however, so let's get back to the origins of life. This book will attempt to enlighten you on some of the latest theories about the chemical origins of life on our planet. We may never know exactly how life got started, but we certainly are making more than educated guesses already... ■

What is Life?

How do we define being alive, what really is life?

You often hear of people talking about searching for life out there in space, and going to Mars to find life, or listening to radio signals to find life… it all seems so pointless sometimes because when we are really honest, and sit down and take a good hard look at what we know about Life, we realise that we have a grand sample set of one. Yes, all those billions of species we mentioned in the introduction may look amazingly different and complex, but when it boils down to it, that's basically just a single sample of life – we share most of our DNA with everything else that's alive on the Earth.

Life on Earth is really just one family of life that we know, and it may be very akin to other forms that we find "out there", or, given that conditions on different planets might not have been the same, Life there could be totally alien to us. A wild way to imagine it would be to think of the rocks on Mars as alive, and examples of Martian life forms – would we even recognise a life form like that if we encountered it? In turn, if a life form like a rock (with a life cycle of millions of years) met us, the chance that they would notice us would be about as much as you noticing one specific droplet of rain (out of billions) during a downpour.

So what is it?

Definitions of the word "life" vary, depending on how it's used in a sentence. For example, "Do you think there is life on Mars?", is a definition that means anything from bacteria to aliens to forms of "life" we have never encountered or even thought about. It literally could be anything!

Image Credit: Threadless.com

Why don't you get a life?

"Is it alive?" is another way of asking if "this thing has life", and usually, this means that you could do something to take away the "life" inside this thing which would make it dead, or "lifeless".

"Why don't you get a life?" is probably the most often used one we hear (especially us geeks). It's a totally different meaning that's pointless for this book.

The one most relevant to this book is actually the first one, and not the second – even though life struggling to not become lifeless is the entire basis of the ecology of the history of Earth. The reason the second example is not as important as the Mars example is because now that we understand evolution, we really have to rethink our definitions.

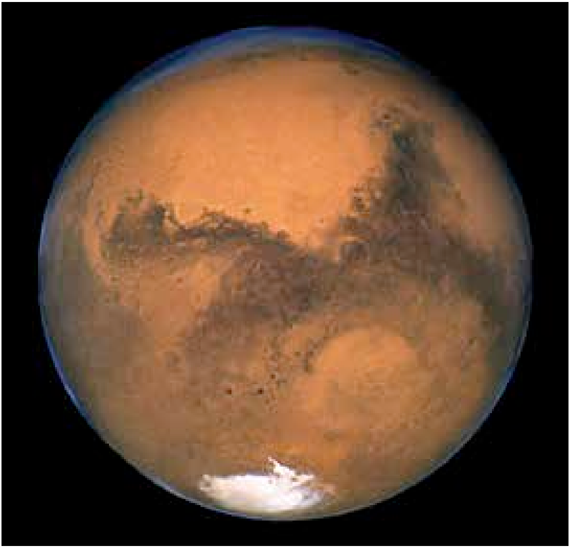
Life and the living

Expanding on the second example above, the property of being alive, and thus dying at some point, as an organism is usually looked at as individuals. Here, the individual is the one that reproduces, lives, dies, etc. However, think about it, you are an individual, yes? However, you are made up of trillions upon trillions of cells. Some cells form one organ, some form another, you have skin cells, stem cells, neurons, and whatnot. Cells inside you live and die all the time, and once dead they are replaced or used as raw material to make new cells. Sometimes cells grow crazily, and badly, and end up becoming cancer, but they're still alive. They don't count for anything as an individual because they cannot exist on their own in our ecology, but they do live and die...

This is why it's the first example that we stick to...

Is there life on Mars?

If one of the Mars rovers found some skin cell-like things growing on a rock, we would hear a huge NASA announcement that life has been found on Mars... this is because the definition of life that we're



Is there life on Mars? Is it just Earth life that went there earlier?

after for this book is more accurately described as properties than an individual living or dying.

Define it already

So what's our definition of life then? More importantly, what are the properties of life that we're looking for? First up, we feel that for something to be termed as "life" it has to be able to reproduce or "copy" itself. Now, whether this is through cell division, sexual reproduction, or some kind of copying that we have yet to discover, this is an important step towards being termed "life". Another aspect is that we feel that an organism (whether cellular or not, single- or multi-cellular, whatever), needs to have a metabolism. It has to "eat", and thus "survive" in some way by doing something to keep itself energised.

A good way to look at it is to be able to self-sustain using some process of absorbing energy or extracting it from a source, so as to be "alive", failing which it would cease to be alive. This would differentiate what is "life" from what is inanimate, or dead.

Then there's the process of Homeostasis, which is basically a fancy word for an organism doing something to keep itself comfortable. Thus everything from bacteria wiggling away from suboptimal substrates to you covering up when you feel cold is an example of homeostasis.

Cats are by far the most evolved beings, they're always comfortable!

Another way is to look at the above is to consider a response to stimulus. Again, this can be as simple as a bacteria making itself smaller (and thus reducing surface area) when it detects a harmful chemical, to a human baby putting a hand in a flame and quickly withdrawing it because of pain. Even plants react to external stimuli – such as turning their leaves towards the sun so as to maximise the surface area of leaves that get sunlight and thus make food from the chlorophyll within them..

Another way to define life could be to look at how an organism grows and adapts to its environment, and has "generations" of imperfectly copied offspring. This process of growth, adaptation and reproduction could be used to define something as "alive".

Our definition, however, is probably all or most of the above.

If an organism is made up of a cell (or many), is able to adapt to its environment in some way, has favourable conditions in which it can grow and prosper, has a metabolism of some sort (it "eats"), shows response to stimulus, can make copies of itself (usually imperfect) and ceases to function at some point due to internal or external factors (can die or be killed), we can consider that organism to be a sample of "Life".

Dissenters

It wouldn't be a science frontier if there weren't people who were against the idea, and no, we don't mean religious nut jobs, we mean other scientists. There are many who don't like the definition of life as we've described it, and there are a couple of reasons why:

Sample set

There those that insist that we cannot make a rule since we only have a sample set of one. If we were to ever find a life form that was different

How do you know what this is unless you've seen other balls as well?

from ours, and thus make the sample set a grand total of two (or more) then we could go about making rules based on similarities between the two life forms. So, for example, if you have a basketball, and nothing else in a totally flat and featureless world, you can't describe it as a "ball", simply because all you would have is one item. Now if you were to come across a cricket ball while you were out bouncing your basketball, then you would now have a sample size of two, and using this you could define what a "ball" is. Then you would arrive at something like "A ball is something that is usually spherical, can be either solid or hollow (filled with air), that is used by humans to play a game of some sort. A ball will usually bounce (some more than others), and is usually used by humans with their hands".

Then of course, while out you might come across a football, and realise that this thing needs to be used mainly with our feet, and would have to change the definition above based on the new information. However, you can't define "ball" with just one sample. This is one school of thought that refuses to accept any definition of "life". They are willing to accept the definition we have given earlier if we add the caveat of "as we know it". So we will please them by telling you about "Life as we know it" in this book.

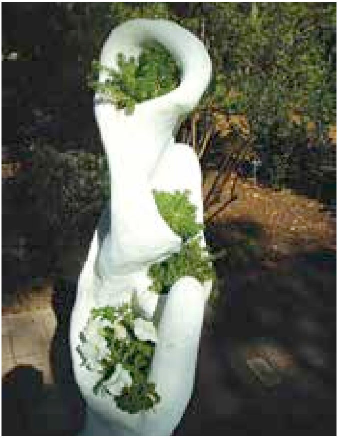
Gaia

There are still others who refuse to accept the definition of individuals at the micro level, and prefer to look at individuals at a much more macro level. So, instead of looking at a bacteria that lives and dies, or the human that bacteria was inside also living and dying, they choose to look at the entire Earth as the living organism, and everything within it just chemical reactions between cells of the Earth. Thus, you are merely a cell of the Earth, and you can either be a good little cell, or a cancerous one, depending on how much carbon emissions you cause… we're kidding… we just went hippie for a bit there…

This idea is not something that people take lightly however, and it has quite a few followers (and no they're not all into free love and mother Earth). The dissenters to this theory are in the majority though, and they're totally dismissive of it as hippie-nonsense.

The original idea for this came from James Lovelock, who is an independent British scientist. Lovelock, now 96 years old, came up with the theory in the 1970s.

The problem we have with going from the individual to the macro-level bio-system to define life is where do you stop? When you go smaller, you stop at a cell. So you could look at yourself as a human, but also a very large bunch of cells. If you zoomed in as close as you could, say, looking at your lung, you would reach a point where the lung cell would be the smallest thing you could apply the definition of life we gave earlier. Beyond that it's all just really chemistry (which is all DNA and RNA are – complex chemical compounds. Thus, in theory, you zoom in from an individual to the point where you reach chemistry. Then you stop.



An abstract sculpture of Mother Earth

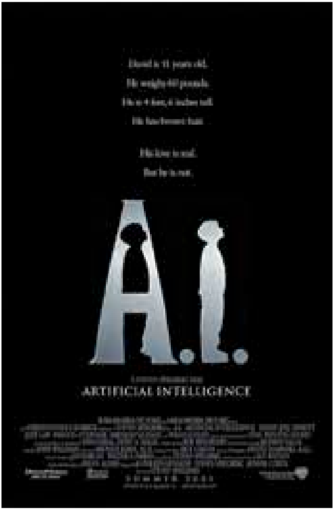
When going the other way, zooming out, you end up involving a lot more of inanimate matter than living things by the time you reach the size of the Earth. In fact, the minute you leave an individual level and zoom out, you hit chemistry (or chemicals and compounds). Even for bacteria, the minute you leave the individual level, you hit the substrate they live in. This is why we don't like this idea of Gaia in general. Why stop at the Earth? Why not the solar system? The Galaxy? The Universe?

Artificial Life?

Many, however, insist that a definition of life will have to include all life, and especially all sentient beings, which may very well be man-made as well. An example is artificial intelligence, obviously, because if computers became self aware, they would perhaps qualify to be termed "life" even if we decide that they are "artificial life", they will still be "life" at the end of the day.

However, AI certainly does not fit into the description we have given above. Sure you could force fit them, by, say, allowing the software to code itself and modify things and also maybe even replicate (thus fulfilling the reproduction requirement of life), however that's not what we'd consider to be "life".

Some will tell you that it is only artificial life that's ever going to encounter life from a different planet, or star, or galaxy, because "natural life" is organic and too vulnerable to the hazards of time and radiation of interstellar (or even intergalactic) space. It's much more likely that we will launch AI-based robots towards the nearest stars as emissaries for humanity. You could well imagine first contact being between robots of two long dead organic civilisations...



All AI wants is to be called a little boy... awww!

The point of all this is to debate whether artificial life can be considered "life", and we're of the opinion that if it was created spontaneously, then it is, but if it's made by an organic species, then the AI of that species is more likely to mimic them than be a truly unique life form. Thus, we'd expect human-made AI to mimic a human, and alien-made AI to mimic the alien species...

Think of it as watching a video of a mother reading to her child with love. What's important in that scenario is the fact that it's an image of a mother, and we will either subconsciously insert the memories of our own mother or of caring for a child, and feel empathy for that video, and that video feels very real. Although the people in the video are/were alive (unless it's animated or special effects, then they're just fictional beings), it's still pretty obvious to anyone that the video itself isn't alive. It's just a video, even if it can bring you to tears, it's still just a video and nothing more. We use that same logic for AI, and call it a projection of ourselves and not really a "lifeform".

Is life viral?

One of the most intriguing questions that scientists have been arguing over is whether viruses (virii?) are to be considered a life form. Viruses can replicate, but of course they use cells of other living organisms to do so, and they have no metabolism of their own (they don't "eat" or have a process of making food). This causes most people to consider viruses as inanimate. Even according to our own definition, viruses cannot be considered alive.

Most studies thus far about viruses have theorised that viruses probably came much later than life. Theories about how viruses got started abound, and many believed that since viruses have genetic material, this material is probably just stolen from the virus' host cell, which meant that viruses had to be things that were created by evolutionary waste – mutations of cells gone very bad; much like cancer.

As time has gone on, however, we've found that this is not really the case. Recent studies have in fact given evidence that viruses are perhaps much older than we previously thought. In fact, researchers now believe that viruses might pre-date modern life on Earth. It is still true that viruses and modern cells share an ancestor in the past at some point, however, it is the viruses that are older than the modern cells!

While we still don't believe we can consider viruses (in their modern form) to be specimens of "life", we still have to investigate them. It might be just wild speculation, but it's perhaps possible that viruses and early life on earth have more in common than we think. Plus, perhaps viruses are just earlier life forms that were cells, but evolved away from complexity towards simplicity – just as species adapt to their environment and surroundings, perhaps viruses adapted to make use of the abundance of life all around them? This is just pure conjecture, however, and thankfully studies are underway to answer these very questions. ■

Early Earth

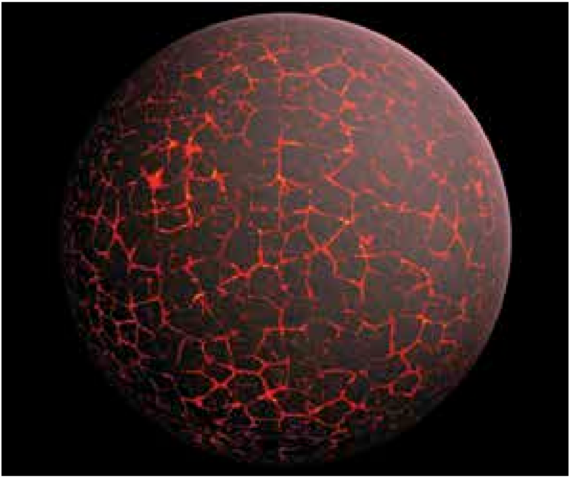
What do we know about the conditions of the early earth?

We start this section with a caveat that we will not go too much into detail about the early Earth, only because we have done an entire *dmystify* on the Earth before this, which pretty much covered all of this already.

What that book didn't cover, however, was conditions specifically related to the chemical reactions that we think could have got life started. We will cover that aspect briefly here.

The Hadean Earth

As the name suggests, the Hadean period of Earth's history was the most hellish. The scientific community is pretty unanimous when it comes to agreeing that this was an impossible place for life to get started. The earth was basically just one big ball of molten rock with no surface to speak of and certainly no liquid water.



The Hadean Earth – literally hell on Earth!

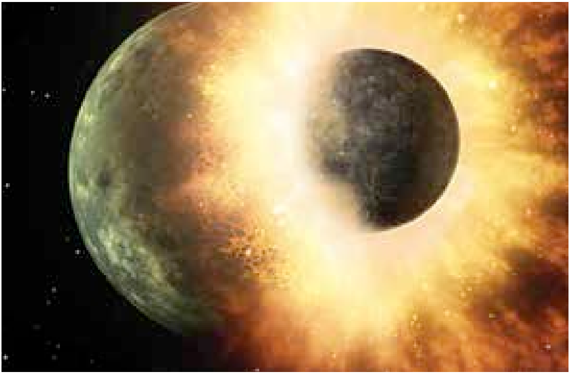
Even when a surface did start to solidify as the Earth cooled, there was still no chance for life to get started because of the constant bombardment of comets and meteors. Many of these comets probably brought most of the water we see on Earth today.

Of course, all of this hellish churn of the planet wouldn't allow life as we know it to get started, however, scientists believe that it was probably very important for life in the long run, because all the churn was causing minerals to be distributed all over the surface of the Earth. This mixing of minerals and compounds and their subsequent chemical reactions are what we think started the chemical reactions that were the precursors of life.

Getting mooned

It was in the very early days of Earth's life that another planet and Earth decided to play a celestial game of chicken – a collision resulted, because planets are pretty stubborn things. The planet (theoretically called "Theia"), would have been about the size of Mars today, and the early Earth itself was a little smaller than it is today. This massive collision – which would have been much more powerful than even trillions of our most powerful nukes all being set off simultaneously – melted the Earth once again into a giant ball of molten rock. Enough "stuff" was ejected into space to form what we see as the moon today. Most of the stuff was ejected at escape velocity, but about 20 per cent stayed in orbit to make the moon.

Of course, over 4 billion years ago the moon was much, much closer than it is today, and would have dominated the skies of early Earth – though there was no life to marvel at that view. The Early moon would have exerted some mighty tugs on the Earth however, and caused some serious volcanic activity.



Theia crashing into early Earth

Another not-so-well-known theory based on observations of the far side of the moon suggests that there may have been two moons formed in the impact. The smaller one eventually colliding with the larger one millions of years later, in a slow speed collision. We might have missed out on some truly amazing sights in our past...

The moon is thought to have formed in a relatively short time after the Theia impact – lower estimates put this number at as little as a month, while the highest estimate is a century, which is still just a blink of an eye in the lifetime of our planet.

Atmosphere

There was no oxygen. We know from volcanoes today that they spew out a lot of carbon dioxide and nitrogen, plus a lot of iron and sulphur based compounds. The atmosphere built up slowly, and this means that with little or no atmosphere in the beginning, Earth was constantly bombarded from space. It's only when the atmosphere thickened that smaller would-be meteorites were burnt up in the atmosphere and didn't hit the surface. When it burns up in the atmosphere it's a meteor, and only when it makes it to the earth's surface, it's a meteorite.

This burning up of meteors also contributes to some chemical theories, because as we know from school chemistry, when you burn stuff, new compounds are born, and when you burn stuff from friction without oxygen, there are some very strange reactions indeed.

The early Earth atmosphere also wouldn't offer too much protection from radiation, which is another ingredient that could have helped the chemical formation of life.

Whatever water was already present on the Earth was certainly either vented out as steam, or was already in the atmosphere as steam. Comet bombardments from the early formation of the solar system would keep bringing more and more ice crashing into the Earth, which would then become steam and cover the Earth with clouds. Once the volcanic and tectonic activity reduced enough for the temperature of the planet to drop enough to allow at least hot liquid water, there would have been rains like nothing living has ever seen. This process took several hundreds of millions of years because it probably happened quite a few times. As soon as the oceans started forming, another comet or meteoroid would fall in towards Earth, crash into it and boil away all the oceans, and the process was back to square one again. There's a good reason why the first 700 million years or so of the Earth's life is called the Hadean period… Hades was the Greek god of the underworld (or basically what other religions know as the devil).

Water

Admittedly, it's still a mystery as to how the Earth got so much water as opposed to say, Venus or Mars. Most people don't know that there is more water inside the Earth than in all of the oceans at the surface. We are taught in school that 97% of the Earth's water is in its oceans, and that all the world's lakes, rivers, ice sheets, glaciers, icebergs, water vapour and groundwater account for a mere 3% of the Earth's water. This is a good way to get people to understand how vast our oceans are, but in strict chemistry terms, it's totally wrong.

Yes, in terms of free water (water that isn't encased in rock or crystals, etc), those figures are correct. However, when it comes to chemical water – H_2O – you could theoretically squeeze a rock and get water from it. This is because rocks contain a small amount of water, and the deeper into the Earth's crust you go, the more we find such rocks. Inside the very molecular structure of rocks, we have found (by studying rocks ejected in volcanic eruptions) that as much as 1.5% of the rock can be water. Of course when we're talking about the Earth's mantle, hundreds if not thousands of kilometres under the surface, we can at best guesstimate the amount of H_2O that makes up the Earth. Turns out the lowest estimate is 1.5 times the water contained in all the oceans, with a higher limit that's a whopping 11 times all the water in the oceans!

It's a good thing all that water is below the surface, and stays there, or else we would truly be a water-world, with no land whatsoever on the surface.

This finding also helps explain how we got so much water to begin with, because scientists have used computer models to find that at most 10% of all Earth's water could have been brought to us via comets across the lifespan of 4.5 billion years. It's much more likely that rocks themselves contained most of the Earth's water, and all of that Hadean period bombardment caused the rocks to melt and boil and give off a lot of their water content. Thus, the oceans of Earth, most likely, were ejected to

Those brown spots are what the comet Shoemaker-Levy 9 did to Jupiter. Imagine what would happen to Earth if it hit us...

the surface from within the Earth itself, during periods of crazily volatile volcanoes.

Regardless of how all that water might have got to the Earth, we do know that it certainly played an important part in the chemical origins of life. Water is by far the most important ingredient of life, and most of the chemical studies done on the origins of life need this basic ingredient.

In the next chapter we're going to look at those chemical reactions, and what we know and what answers we are still searching for... ■

Chemical and biological theories

Here's a look at some of the impressive chemistry and biology done over the years in the search for the origins of life

Although we have never made organic life from inorganic inanimate matter or materials, the search for this method is currently ongoing. There have been a lot of developments in human history, and many scientists are certain that within the current century itself, mankind will finally be able to prove the chemical origins of life. As is true for all fields of science study, however, there are some very ingenious people who we owe a lot to, and what follows is not comprehensive, but is a good start to recognising their contributions.

Ancient beliefs

We have proof going as far back as Aristotle (384 to 322 BC), in the western world, about theories that people had about the origins of life. The idea of spontaneous generation of life was the widely held belief at the time. This is because the scientists of the time observed lice being born from dust, and maggots from decaying meat, etc. Thus, the reigning belief of the time was that life just came about in the right conditions, and it wasn't only the case that an organism could give birth to another like itself. After all, if rotting flesh could birth maggots, perhaps all life was interchangeable in some way. Other examples of the time that life could spontaneously generate were:

You know you shouldn't eat anything that has these in them!

- Aphids were observed to be born from dew drops
- Flies were born in rotting matter and faeces
- Leave hay lying about and rotting and mice appear in it
- Frogs appeared from slime

It wasn't until 1668 (over 2000 years after Aristotle), that Francesco Redi, the Italian physicist and biologist, did an experiment to prove that maggots do in fact come from flies eggs. He took six jars, put raw meat into all of them. Two he left open, two he covered with gauze, and two he sealed tightly shut with cork.

He took two jars each so as to prove that it was more than just a one-off case. As we would now expect, the jars in which flies could go inside, maggots appeared on top of the meat, and obviously the jars which were sealed tight with cork, no maggots appeared at all. It was the jars sealed with gauze that was interesting, because maggots did appear, but on top of the gauze, and didn't live very long, and no maggots appeared on the meat. This proved the direct relation between flies and maggots.

He also did experiments with sealed jars with flies inside that were alive and sealed jars where only dead flies were put in, just to rule out the possibility that the maggots were something that flies carried on them. Redi then went on to observe maggots for a much longer time and see that they indeed did metamorphose into flies, and thus proved that maggots are just the larval stage of flies. This was also supposed to be the end of the the spontaneous generation idea.

Aristotle (right) pictured here with Plato (left) taken
from the painting “The School of Athens” by Raffael

Of course it wasn't, because religion still had a hold on science of the time and spontaneous generation was the belief of religion as well.

Louis Pasteur

Experimentation continued to try and find instances of spontaneous generation, and often that experimentation was flawed (in hindsight). Félix-Archimède Pouchet, in 1858, announced to the scientific community that he had demonstrated the existence of microscopic organisms that had spontaneously generated from no "parents" that were similar to themselves. He had done this by boiling water, passing it through mercury, then introducing oxygen, and finally some hay that was kept in a glass bulb and heated to very high temperatures in order to kill the living cells (or germs) on it.

After a week or so, the hay had a mouldy substance on it, which Pouchet declared was proof that spontaneous generation was a fact.

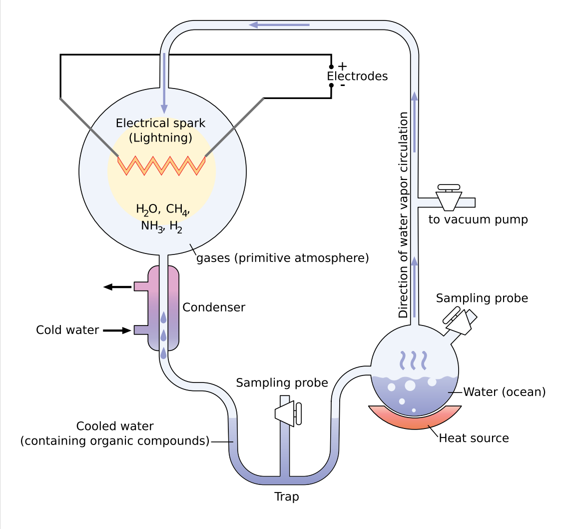
Pasteur, who was working on a lot of microbial fermentation and vaccinations was drawn into this because he realised that Pouchet was indeed wrong. He went on to prove that what Pouchet had overlooked was the "germs" in the mercury. He showed this in many ways, but the most breathtaking at the time was when he totally darkened a room and shone a beam of light to show dust particles dancing inside the beam. Although all of us probably wouldn't be wowed by this anymore, at the time it was like a magic show for people.

You can thank Louis Pasteur for all the pasteurized foodstuff we consume

Pasteur then went on to do experiments to show how to properly kill off germs, and how, when germs were properly killed, there was no spontaneous generation. And yes, this work led to the "pasteurisation" of milk which gave it a much longer life before it spoiled. It is thanks to his original idea, and the improvement of germ killing techniques that so many of us get to eat and drink food that is transported to us across large distances.

Miller-Urey

The two scientists Stanley Miller and Harold Urey conducted an experiment in 1952, trying to mimic what was then thought to be the conditions of the early Earth. Their aim was to recreate the early Earth in a laboratory and see what happened. Thus, they put methane (CH4), ammonia (NH3) and hydrogen (H2) into a sterile flask that was connected to another 500 ml flask that contained water. This water was heated to encourage evaporation, and water vapour was passed into the first flask containing the chemicals. Sparks were passed in this gaseous mix to simulate lightning, and the flask was repeatedly cooled to allow the water to condense and collect at the bottom. After a week of operation the water was removed but sterilised to prevent microbial contamination. In what was left at least five amino acids were recognised. Much later, in 2007, scientists unsealed one of the sealed vials of this experiment,



The Miller-Urey experiment diagram

and actually found over 20 different types of amino acids! However, the composition of the early Earth is thought to be very different from what was theorised at the time of the Miller-Urey experiment. Although they did prove that it is pretty easy for some building blocks of life, such as amino acids to form in nature, the result is a lot less relevant to modern theories of Abiogenesis.

Biogenesis and Abiogenesis

Thomas Henry Huxley, also popularly known as Darwin's bulldog, was a British biologist who was most famous for being a staunch believer in evolution, and a very vocal proponent of the theory of evolution. It is with reference to Huxley that Richard Dawkins has earned the present day informal title of "Darwin's Rottweiler". Huxley is also the one who came up with the term Abiogenesis. He also used the term Biogenesis, but unknown to him, it was also a term used informally by the British neurologist Henry Bastian to mean something totally different. In the context of our book, however, it is Huxley's definition that we are interested in.

Huxley used the term Biogenesis to refer to the reproduction of living things, in whatever different ways living things reproduce (cell division, laying eggs, carrying their offspring, asexual reproduction… whatever…). When using evolutionary theory to go backwards, and thus suppose a chemical beginning of life, it was obvious that he needed to have a term that was the opposite of Biogenesis, and thus he came up with Abiogenesis.

Abiogenesis pretty much means life from non-life, or basically the entire reason for this book. We didn't use it in the title, and chose to

Thomas Henry Huxley, aka Darwin's Bulldog. We wonder how he acquired that nickname... not!

call this book Life so as to appeal to a wider audience, and not scare away readers, but certainly "Abiogenesis" is the more accurate title.

Space organics

Life would need a lot of organic stuff to come together before it could have got started. All of that organic stuff was available in the atmosphere of the early Earth, and surprisingly, is even available in space. We're not just talking about space billions of years ago, we're talking about space right now, there are organic molecules and clouds floating about in interstellar space.

Thanks to experiments similar to the Miller-Urey one we mentioned before, and the more recent finding of interstellar organic clouds, scientists are hypothesising that in essence, the early Earth certainly contained a much higher amount of organic building blocks of life than we've previously thought of. If these building blocks weren't all formed in the atmosphere because of lightning and radiation coupled with carbon-based compounds, water and nitrogen, then they certainly could have rained down on Earth from space. This process of organic stuff raining down on planets is called pseudo-panspermia.

Panspermia

Panspermia is a very popular theory, and is often used in some form in science fiction to describe how life got started on Earth.

Nicknamed Black Beauty, this meteorite found in Northwest Africa has been confirmed as a piece of the Martian crust

It is somewhat the central theme of the movie *Promethueus*. Of course, the theme is dealt with more in a religious way, where an alien sacrifices himself to bring life to our entire world – the old ultimate sacrifice story. Why a race advanced enough to travel across a galaxy cannot just inject DNA into a dead Earth, and instead needs an alien humanoid to drink some potent stuff that breaks apart his body all the way down to the genetic level is always going to be a mystery to us.

However, the idea of panspermia is not all about badly written scripts for science-fiction movies. In fact, there's a very real science to it. For example, we have found rocks on Earth that originated on Mars. This happens when a planet is hit by a meteorite, and blasts off chunks of rock at escape velocity. Depending on the direction and speed of ejection from the planet, those rocks can make their way towards other planets. There is no doubt that over the four-and-a-half billion year lifetime of our solar system, the inner planets alone have exchanged tonnes of rocks. Not just rocks from mars have found their way to Earth, but rocks from Earth have certainly found their way to Mars. The impact that killed off the dinosaurs 65 million years or so ago has no doubt sent off quite a few tonnes of rocks into space towards Mars and Venus. It would not at all be surprising to scientists if they found life on Venus or Mars that was genetically similar to life here on Earth. The only argument we'd have is about which planet seeded which.

Lithopanspermia

This is the type of panspermia we were talking about just before. This is where organics or bacterial life or spores embedded inside a rock could be transferred across interplanetary space. In order for this to be possible, however, there would have to be three very extreme conditions that life would have to survive. The first, obviously, is the process which would eject the aforementioned rock into space. In order to be sent off into space at escape velocities, you would expect there to be a rather large bang involved, with a huge amount of heat and other radiation. The bare minimum energy required to do this naturally would be an impact that would be more powerful than any nuclear weapon we have ever developed. Plus, the energy required would be really high because the rock itself would have to be of considerable size. That's because of the second and third conditions.

The second extreme condition that life would have to endure is a journey of millions of kilometres in space, if not billions. The shortest distance between Earth and Mars is 225 million km, and that's in a straight line at a very specific time in their orbits when they make their closest approach. The farthest away Mars is from us is about 400 million km, just to give you an idea of how much the distance ranges. For a rock to be ejected out from Earth and then travel around the sun and intersect Mars orbit and hit it would probably involve far more than even a 400 million km journey. It could sometimes be as high as billions of km that a rock had to travel before it hit the other planet. Sticking to the minimum distance of 225 million km, a rock would still take a considerably long time to get from here to there. We know that bacteria could survive for quite a few years inside the rock, because it would be shielded from the sun's radiation and the frigid cold of space. In fact, not just bacteria, but even tardigrades have been shown to survive some pretty harsh conditions in space – tardigrades have survived solar radiation and space conditions for weeks!

The third extreme that a rock would have to survive would be impact into the other planet. Because Mars atmosphere is just 1% of Earth's, a rock from Earth to Mars might have an easier time than one going the other way. We know that a lot of small rocks get burned up in our atmosphere and never reach the surface of the Earth because of the thickness of our atmosphere, so one that does would have to be a pretty hefty sample. It would then have to survive impact as well.

Despite how bleak the prospect sounds of finding Martian rocks on Earth, we have identified over 100 of them already. The latest count is 132. That's 132 confirmed Martian meteorites found on the surface of the Earth by humans, out of the 60,000 or so other meteorites we have found so far. Remember, finding a Martian rock on Earth is essentially like looking for a specific needle in a stack of billions of needles. The fact that we have found 132 such needles, indicates that there are a lot more of those needles than we previously thought!

Radiopanspermia

This is the theory that tiny particles can be propagated in space because of the radiation pressure of stars. This is pressure felt on the surface of an object in space because of electromagnetic radiation from a star, and although is a very miniscule force in terrestrial terms, it is enough to cause motion in space.

A common example that's usually given to explain why radiation pressure has to be accounted for is the example of the Viking spacecraft (Viking 1 and Viking 2) which were sent by NASA to Mars. Had the effect of radiation pressure not been taken into account, the spacecraft would have missed Mars orbit by about 15,000 km. This is because the radiation pressure of the sun is enough to push a spacecraft on a 225 million km journey off by a miniscule angle of 0.004 degrees. In astronomy and astronomical calculations, a seemingly small error of angle gets magnified the farther away something travels. If it's a mere 15,000 km off target on its journey to Mars, an error of 0.004 degrees would result in missing Pluto by 523,600 km (for a 7.5 billion km journey). To our closest star, Proxima Centauri, this would result in an error of 2,802,300,000 km, or 2.8 billion km (Proxima Centauri is 40.14 trillion km away from us).

Back to the topic, the theory of radiopanspermia suggests that it would be possible for radiation pressure to act on things smaller than 1.5 micrometres (one thousandth of a millimetre). Because the effect of radiation pressure is most on things smaller than this, and the only life forms we know of smaller than this that are also capable of such a trip are bacterial spores, we think this to be only a very remotely possible scenario of panspermia. It's not impossible to imagine, it's just highly improbable. Science history, however, has taught us to be wary of dismissing the improbable, because we just don't know enough yet.

Accidental / Directed panspermia

Now we come to some very interesting theories, that almost certainly sound like science fiction.

Accidental panspermia is the wild suggestion that life on Earth may have got started as a result of waste products left behind by alien visitors to an ancient Earth. An alien species passing through might have left some rubbish that contained microbial life forms which then took over the previously dead planet, and resulted in us 4 billion years later. Now, now. Before you scoff at this theory, remember that eventually we will get to Mars, and we will, no matter how careful we are, leave some waste lying about there, which very well might contain bacteria. Remember that 4 billion years from now,

We've left a lot of junk behind when we visited the moon, some of it probably contained bacteria. Anywhere else and it would stand a chance of survival – like Mars!

the Earth will have been destroyed by a growing sun as it starts to burn itself out. The "goldilocks" zone we find ourselves in will have moved outwards to where Mars sits now, and the Earth will suffer the fate of Venus, or Mercury, and be baked dead. Assuming we don't wipe ourselves out before then, we will probably have left Earth for greener pastures in different star systems because Mars would not be of interest to us. We may have the technology to take everyone, or we may just leave billions to die on Earth while the best of us go and colonise another solar system many light years away. Four billion years from now, the Earth will be as hostile to exploration as Venus is today, and Mars will be getting all nice and toasty, and perfect for life. If the bacteria we left behind on Mars was able to get a foothold and adapt to Martian climate and minerals, we could well imagine intelligent life sitting and pondering their existence. Who wants to bet there will be some Martians reading a theory about accidental panspermia by aliens being their origin story, and them scoffing at it? Still think it's a ridiculous theory?

Directed panspermia is in fact what we were talking about when we mentioned the movie *Prometheus* earlier, because it literally means sending life to another planet on purpose. This act of seeding life on another planet across the stars (or the solar system) has been explored very often in science fiction, but it's not totally out of the realms of possibility. Although we have no evidence of, and certainly do not think this is how life came to exist on the Earth, it is quite probable that we might someday send off a ship with dormant life to seed a planet far, far away from us. Another aspect that science fiction covers often is the destruction and desolation of earth, and how we as a species rush to try and preserve life when all seems lost. Take for example a scenario where we detect a massive comet headed straight for us, which would result in total annihilation of not just the Earth but also the moon, we might rush to save the species by sending off life to Mars. Although we might try to save humans, by sending a chosen set of humans to colonise Mars, given the unlikely survival odds, we may be more successful if we sent some of the bacterial extremophiles to, say, Europa (Jupiter's moon), where we know that there is liquid water under the surface, and volcanic activity.

Extremophiles?

Now we come to some very interesting biology. Over the last century or so, we've been humbled quite a few times when it comes to finding life in unexpected places on Earth. Every time we thought we knew enough about life to know where we wouldn't find it, there it would be... Life is pretty much all pervasive on Earth.

We've come up with a term for life that survives is what we think is really harsh conditions, and that term is extremophiles. The name comes from a mix of the Latin term *extremus*, meaning extreme, and the Greek word *philia*, meaning love. Basically, things that love extreme conditions.

The conditions we're talking about include high and low temperatures, pressures, pH levels, etc. It is true that most life on Earth wouldn't be able to survive in the conditions that extremophiles thrive in.

There are way too many types of extremophiles to list all of them here, but some of the important ones are acidophiles and alkaliphiles (things which live in pH levels of under 3 and over 9 respectively), anaerobes (bacteria which live without oxygen – to some of them oxygen is poisonous), cryophiles (temperatures under -15 degrees centigrade) and thermophiles (can thrive between 45 and 120 degrees), halophiles (high salt concentration) and osmophiles (high sugar concentration), barophiles (high pressures), and then the polyextremophile (organisms which have more than one extremophile trait, such as thermoacidophiles, which survive in high temperature and acidic substrates).

Tardigrades (water bears) and other hardy creatures are not considered extremophiles. They are more hardy creatures than extremophiles, because although they can survive harsh conditions, they do not thrive in them, and the longer the exposure to the conditions, the lower their chance of survival.

Reverse panspermia

Needless to say, extremophiles are the reason why the theory of panspermia is still popular. However, it's reverse panspermia (life going elsewhere from Earth) that we think to be more plausible, and we wouldn't be surprised at all to find life on Mars, Europa or Triton that originated on Earth. Computer simulations (which are getting more and more accurate and complex as computing power increases) have shown that it is almost certain that rocks blasted away from Earth due to impacts within the last 4 billion years (when life existed on the planet) have landed on other planets or moons. It's not surprising that most of the Earth rocks sent off into space return to Earth, but about 100 times more rocks reach Mars than we previously thought, and simulations have shown rocks quite easily reaching Jupiter and it's moons. Recent simulations have shown that rocks reaching Saturn and Titan are also very much in the realm of possibility.

Chemical evolution

Most dissenters of the theory of abiogenesis (usually for religious reasons), try to find fault by pointing out that the Miller-Urey experiment was a farce, because although it did produce amino acids, it used the wrong supposition for conditions of the early Earth. However, although they are usually quick to debunk the Miller-Urey experiment, they conveniently ignore all the work done in the 70 years since then.

What science has done since then is prove chemical evolution (like life, even chemicals evolve). In chemical systems there is replication, variation, and even natural selection. Plus, scientists have been able to demonstrate RNA replication as well. More on that in the next chapter. ■

Life is inevitable

What if all we are thinking about all of this the wrong way. What if life itself is inevitable?

In this chapter we will look at the more recent theories and experiments that are being done across the world to try and find the answer to how chemical evolution happened. Note that for most scientists, it's not a question of "if" abiogenesis happened, or "if" chemical evolution let to the beginning of life on Earth, but "how". Science is pretty certain that the only explanation for life getting started is in fact a chemical origin, and nothing else. Even if panspermia resulted in life coming here from Mars, that life would still have to have a chemical beginning on Mars then. However, panspermia is not considered a very serious proposition, and it is far more likely that life began on Earth itself.

Living vs nonliving

Traditionally, science has thought of the difference between living and nonliving things as a big divide. We think of it as a huge step

Now that's a rock that's alive!

that has to be taken to bridge that divide, and thus we start from very basic non-living things and try to arrive at very complex living things, and we miss out on the millions of evolutionary steps in the middle. The reason why it's so hard to imagine this gap as being bridgeable is because most of us will think of simple ingredients such as carbon, or oxygen, and then think of living things such as us, or dogs, or even seemingly simple creatures such as worms, whereas nature itself could never build a worm in a test tube using only chemicals. Not in a trillion years of chance would that happen even once. Nature wouldn't be able to build a simple cell from just elements, it would need to take multiple steps to go from elements to compounds to more complex compounds etc until it arrived at a cell. Thus, expecting us to be able to do so is just ridiculous. It's certainly not possible with the technology we wield today. Perhaps in a 1,000 years we might be able to throw some stuff into a chamber and press a button and get a pet dog out of it, but for now, we are certainly not capable of anything even remotely that magical.

What is "Alive"

The difference between the living and the nonliving is usually measured in terms of reproduction, or death, or cycles, or metabolism, etc. We tried to define it ourselves in the first chapter of this very book. Now, some interesting new ideas from cutting edge science, bordering on philosophy, are arguing that even the differences between living and nonliving things are just in our head.

We tend to think of the difference as the difference between us and a rock. Even if it's not us and a rock, then we tend to think of it as a bacteria and a rock. Usually it's a rock we think of, because nothing is more cold and dead to us than a rock. A large rock will sit there, for millions of years, doing nothing but weathering slightly because of winds and rains. However, as geology will tell you, forget rocks, even entire continents are never stationary. Given enough time, everything changes.

Time

Our perspective of the world comes from time. We look at it in our own relative time, because we live and die in a specific set of time. To us, a tree is relatively dead and lifeless, and yet we know that a tree is "alive". If we look at being alive as having ongoing chemical processes at any time scale, then yes, even a rock is alive. Tiny amounts of radioactive carbon are decaying inside a rock, and changing, and on the outside, weather is also causing it to change. Just because the timescale is something we cannot fathom, or witness, doesn't mean it doesn't happen. We have scientifically proven that it does indeed happen. Much like we have proven that trees do really do things on a daily basis, even though they just look like the sit there, leaves flapping in the breeze... so is "life" just a matter of perspective and relative time? Is a rock more alive to a tree than a rock is to us?

Metabolism

All of biochemistry is based on a simple formula. As an organism, you need energy to survive, and how you get your energy is from electrons via chemical processes.

Some release energy by giving electrons away, which can be called reductive organisms, and others take on electrons to be oxidative organisms.

Now another way to slice all organisms on Earth is to look at whether you need other organisms to survive, or can go it alone in the world. Some of us cannot survive without other organisms – whether you're vegan, vegetarian, non-vegetarian or on one of those fancy new diets, you are a heterotroph (which means you need other organisms to survive – eat, reproduce and thrive). Many forms of bacteria or algae are autotrophs – can survive if even all other living things on the planet died out right now (so long as the environment doesn't change).

You don't need to be Einstein to see where we're going with this... Since oxidative life obviously didn't exist until much later when life itself created oxygen (there was no oxygen on earth until living things created it), the first life forms must have been reductive. Also, since the first life forms could not have "eaten" other life forms to survive, they were also obviously autotrophs. If we are going to understand the origins of life, we have to look at the reductive autotrophs of today as the clues or descendants of the earliest forms of life.

Time Travel

Instead of looking at the tree of life and trying to find which species begat which other species in a very biblical sense (we're using biblical terminology on purpose here), we should perhaps be looking at what we have today, across the various conditions that we have on

Earth, and correlate them to the environment of a past time on Earth to try and understand how life evolved and perhaps, how it started off. Thus, the reductive autotrophic life that thrives at undersea volcanic vents is probably the closest cousin to the first life on earth.

Not special

Another aspect we perhaps mistakenly give to life is to award it a badge for being special. We think of it as a rare occurrence, or a special circumstance, but what if it wasn't? If we look at the world like a simple chemical reaction, we perhaps might arrive at the same answer, but perhaps in a different way. Our bias of life being special, or needing something special to occur, or to occur by chance, is perhaps us trying to fit a square peg in a round hole. Yet we seem to keep hammering the peg in hoping that the hole itself will yield. Perhaps life isn't special or by chance, perhaps life itself is inevitable.

Inevitable? How?

We think of things as cause and effect, and then we try and find "how" (or sometimes even "why") the cause even happened. We know the effect, because we're here, and thinking about the cause. However, think about it as a chemical reaction for a moment.

There's a lot of Hydrogen in the universe. Hydrogen has the properties of wanting to give away its electron and bond with other

Just as you roll downhill when Zorbing, perhaps life is just the chemical version of rolling downhill

elements. The early Earth had a lot of carbon dioxide and a lot of hydrogen, but chemical processes aren't very good at splitting carbon dioxide to allow the hydrogen to bond with the carbon atoms to give methane (CH_4) or oxygen to give water (H_2O). Actually, since we're talking chemistry, there are a few chemical processes that are very efficient at converting carbon dioxide to methane and water, or other carbon compounds and water. Those chemical processes are pretty much what we call life (anaerobic life, to be more precise).

Finding balance

Chemical, geological, meteorological, electrical, etc., systems try and find balance. If you have a cathode and an anode, and you keep building up charge, eventually there will be a spark between them to transfer charge. This is because they try and find balance. Water does it all the time, and that's why we have rivers. Weather systems and seasons are examples of the atmosphere trying to find balance because of the external effects of the sun. Volcanoes erupt because they have to release excess pressure caused from under the surface by spewing their guts out above the surface. Nature finds a way to find a balance. Could life just be nature's way of finding a chemical balance?

Thriving

As we mentioned before, when things start building up, nature finds a way to restore equilibrium. When there was too much carbon dioxide in the atmosphere, and way too much volcanic activity happening, nature paved the way for a chemical reaction to come along and restore the balance. It's obvious that chemical reaction would be

It’s called Death Valley for a reason!

self sustaining, and perhaps be a chain reaction. In fact, the term “thriving” that we use for life is nothing more than a chemical chain reaction occurring based on the availability of the resources needed to keep that reaction going.

Even on a macro scale this translates well. Humans can’t thrive when there are no resources that humans need in a certain area. Thus, deserts are the most sparsely populated areas on Earth. Of course there is some life that finds a niche in even a desert, but without the resources, most other life cannot survive there. Along the banks of a silt rich river, however, human, animal and plant life has been known to thrive, because there are enough and more resources there.

Not chance

This new theory is way better than the theory of chance because the evidence does not point to chance being a deciding factor in the evolution of chemistry or life. If life arose by "chance" then it is much more likely that life would be wiped out. The fact that life persists is

Life isn't a game of dice

not because it is at odds with the world, but in fact it exists because it is inevitable on this world, and perhaps others like it.

Of course, we still don't know what "life" would look like on other worlds, but perhaps we could look at those worlds to try and find chemical chain reactions that bring equilibrium and change to that world, and that would be the equivalent of life on that planet or moon.

Not panspermia

This new way of looking at life, pretty much rules out panspermia, because it doesn't look at life like a virus, or a plague, that goes to a new world to infect and take hold of it. If life is in fact an inevitable outcome of chemical imbalances in a system, then the only way life could "thrive" on a new planet is if that planet had exactly the same imbalance. For example, assuming such things exist, take an anaerobic Venutian microorganism (bacteria that lives off of carbon dioxide from Venus), shove it into a rock, transport it for hundreds or thousands of years across space and crash it into the Earth, safely, and then as soon as the rock splits, the Venutian organism either dies of oxygen poisoning, or cannot get enough energy to reproduce and take hold because of the low carbon dioxide in our atmosphere.

The theory of panspermia makes too many assumptions, and one of them is to assume that a microbe will magically find a niche that it's capable of thriving in on a totally different planet, which is a theory that, honestly, has the odds stacked against it.

Think backwards

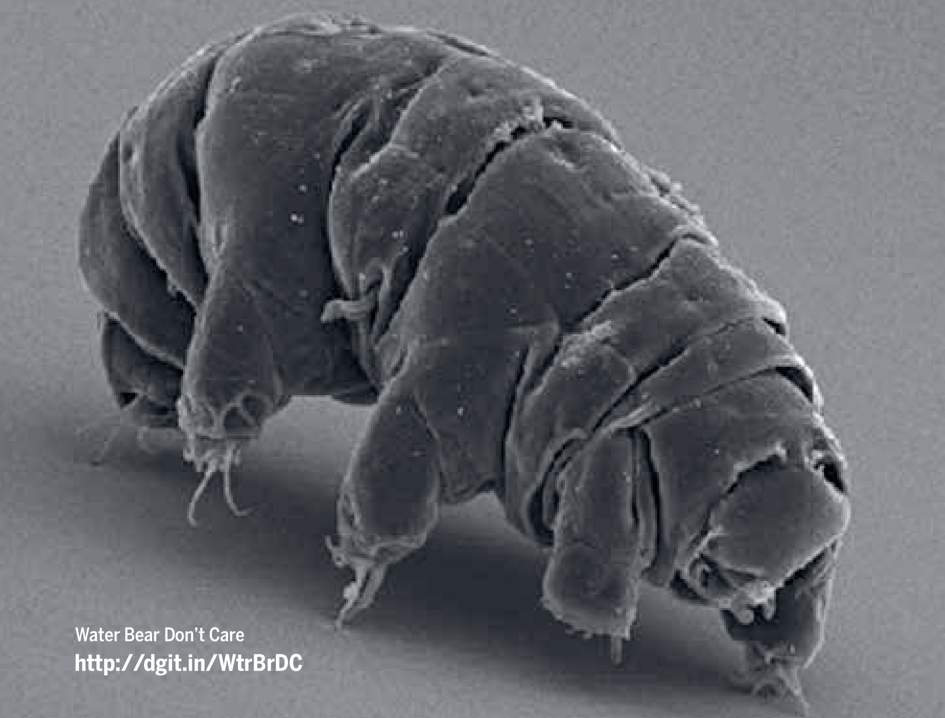
While we've got you thinking backwards, you should also rethink the things we take for granted. For example, we think that life came first, and then it developed a metabolism. Basically, we think of eating to get energy as a way of living. So anaerobic bacteria consumed carbon dioxide to make carbon compounds and water in order to survive. That's the way we're taught to think in school, but it's perhaps more likely that it is metabolism that came first, and life later. So it's not the bacteria eating carbon dioxide to live, but the carbon dioxide needing to be eaten that causes bacteria to live! If that seems like a strange thought, congratulations, you're a normal human being. We are programmed by evolution to put ourselves at the centre of everything, when in fact we are probably inconsequential to the overall biosphere. We think of life as special, when it's probably just a chemical reaction, and nothing more.

If this subject intrigues you. Remember to check out the learning resources we have recommended at the end of this book.

As always, remember to send feedback and your thoughts to *dmystify@digit.in* and let us know what you thought of this book. We also welcome suggestions for what you want us to cover next. ■

Resources and reference material

- *http://dgit.in/LifeOrgn*
  A talk by Dr Eric Smith, whose ideas influenced us to write the last chapter of this book
- *http://dgit.in/Abiogns*
  A primer on Abiogenesis
- *http://dgit.in/LifeBgng*
  Origins: How Life Began - With Neil deGrasse Tyson
- *http://dgit.in/LifeOnErth*
  Nova Documentary on the Origin of Life
- *http://dgit.in/CellLife1*
  http://dgit.in/CellLife2
  http://dgit.in/CellLife3
  A series of indepth technical lectures by Nobel prize winning scientist Jack Szostak on the origin of life (biology knowledge required)
- *http://dgit.in/OrgnOfLife*
  Lecture by Dr Nita Sahai - From Geochemistry to Biochemistry
- *http://dgit.in/WhtIsLife*
  ASU Origins - What is life ■



Water Bear Don’t Care
http://dgit.in/WtrBrDC