
Popular Science Magazine for Students and Their Parents
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IN WHICH EPOCH DO WE LIVE?
HOW CAN WE STOP THE END OF THE WORLD?
WHAT IS A PETRI DISH?
HOW DOES SOAP WORK?

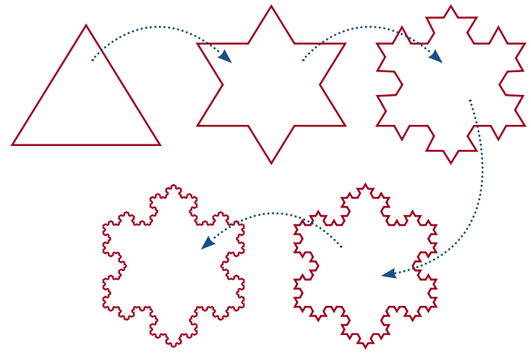
TABLE OF CONTENTS

In everyday life, we rarely hear the mysterious word “fractal,” but we encounter them on a daily basis. Trees, mountains, smoke, plants, and even the circulatory system have fractal structures.

Fractals can be applied in various areas: from image compression algorithms to the study of blood vessels of living organisms.
So what is a fractal?

What Is a Fractal?

In the language of mathematics, a fractal is a set with the property of self-similarity. In other words, each member of the set is an exact or approximate copy of a part of itself. One of the simplest examples to help us understand fractals is a **Koch snowflake**. Let’s build one first for ourselves:



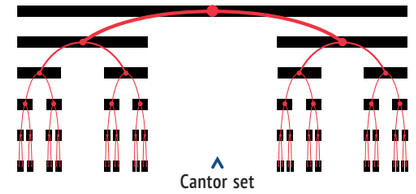
1. *Draw an equilateral triangle.*
2. *On each side of the triangle, draw more equilateral triangles.*
3. *On each side of the smaller triangles, draw even more triangles, and so on.*

The Koch snowflake occupies a limited area. For example, it can be limited to a circle of a certain length. But meanwhile, the snowflake has an infinite perimeter(!). Say that the triangle’s side is one whole. Then, with each step, its length (l) increases 4/3 times. It is easy to derive the ratio of the length of the side

at n^{th} step, $l_n=\left(\frac{4}{3}\right)^{n-1}$

As n approaches infinity, the side length will also approach infinity.

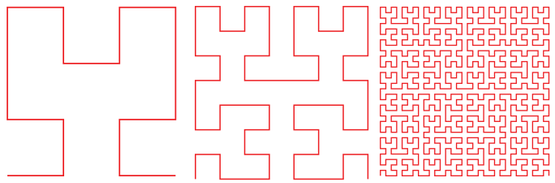
The Koch snowflake is a **geometric fractal**, as are the **Cantor set**, the **Sierpiński triangle**, the **Peano curve** (space-filling curve), and many others. It was with these models that the theory of fractals began in the 19th century, due to the fact that the properties of self-similarity are most apparent in geometric fractals.



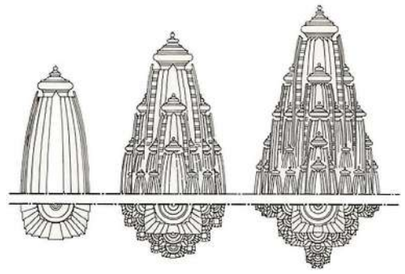
Cantor set

Fractals are described by simple rules, which must be performed repeatedly. The advent of the computer caused a revival of interest in the study of fractals, as they were perfectly suited to perform such operations.

Fractals are a highly abstract mathematical concept, but, surprisingly, we frequently encounter objects in nature which possess their main property — self-similarity. This is linked to two main trends in the practical application of fractal theory. Firstly, there are attempts to copy a natural fractal object using a simplified mathematical model. Computer animation achieved great results in this trend. Secondly, there are efforts to analyze a natural object and reveal the fractal structures within it.



Peano curve



Hindu temples have self-similar fractal structures, wherein separate parts resemble the whole. The central tower represents the deity Shiva, and the groups of similar smaller towers are the endless repetition of the universes in Hindu cosmology.

The Khajuraho Group of Monuments

Fractals in Nature

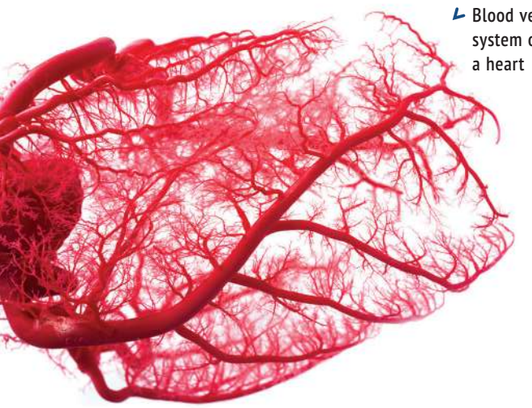
Corals, sea stars, hedgehogs, broccoli, coastlines, mountain ranges, and snowflakes all possess fractal properties. One of the clearest examples of this structure is a tree. Many branches extend from the trunk of the tree, and from those, smaller branches, and so on.

The tree possesses the main property of fractals, self-similarity: each branch is similar to the whole tree. The human circulatory system is also arranged in a similar way. From the arteries, thinner vessels, called arterioles, extend. From arterioles, capillaries extend, which are the smallest of all vessels. Due to these properties of blood vessels, scientists have been able to study and explain various anomalies in the human body.

LEONARDO'S RULE OF BRANCHES

In the 14th century, **Leonardo da Vinci** developed a rule about the thickness of tree branches: "all the branches of a tree at every stage of its height when put together are equal in thickness to the trunk." Scientists have not found an exact explanation for this phenomenon. Some associate it with the transportation of water in the bark of the tree, while others believe it is due to the tree's resistance to external mechanical influences.

Leonardo da Vinci's drawing



Blood vessel system of a heart

Coastlines are the most unusual example of fractals. If in the rest of these examples, a person could visualize the object in its entirety, then coastlines are more complicated: standing on the ground, you can only observe a small portion of the shore.

Lake Atatürk is a water reservoir created by the Atatürk Dam. It is the third-largest lake in Turkey, second in size only to the Tuz and Van reservoirs. This photo was taken by astronaut Anatoli Ivanishin from the International Space Station.

The Coastline Paradox

Measuring the length of a shoreline is an extremely difficult task. First, it is not a straight line; the shoreline bends and curves anywhere from a few yards to a few thousand miles. The coast has so many bends of varying lengths that it is difficult to find and measure them all. Because of these variances, if you divide the coast into segments of 25 mi and count the total length of the segments, the result will be radically different from what you get if you divide the coastline into 50-mi segments and sum those. English mathematician **Lewis Fry Richardson** encountered this paradox in 1951. He noticed that Portugal thought the length of their land border with Spain was 987 km (≈613 mi), while Spain thought it was 1,214 km (≈754 mi). They solved this problem by adopting the smallest fragment as a unit of measurement. For example, if the length of a coastline is measured in miles, then small bends which are much less than half a mile long are not taken into account.

Unit = 124 mi
Length ≈ 1,491 mi

Unit = 62 mi
Length ≈ 1,740 mi

Unit = 31 mi
Length ≈ 2,113 mi

WHERE IS FRACTAL THEORY APPLIED?

Image Compression

A fractal algorithm for image compression has a high compression ratio: the image becomes much smaller in size, which saves memory on the computer. The compression ratio when using a fractal algorithm is roughly comparable to the most popular compression method, JPEG.

The essence of the JPEG function is the detection of "self-similar" proportions of the image. This makes it possible for the image to increase in size later while preserving its quality.

The original image, increased to 512x512 pixels

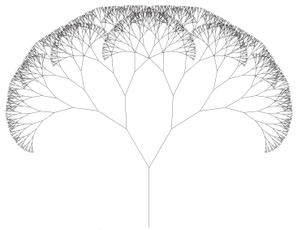
The image, compressed using the fractal method,and then increased to 512x512 pixels

Example of a stochastic fractal in computer graphics

Art

Clouds, trees, flowers, mountains, the sea, and many other natural objects that can be seen in computer games and cartoons are generated with the help of fractal algorithms. When using the fractal method, you do not need to draw each detail of a graphic object separately (a tree branch, mountaintop, or flower petal); you can simply set the initial parameters of the algorithm, and the rest of the work will be done by the computer. Because of this, it is also possible to change an object quite quickly just by altering the initial parameters of the algorithm.

> Fractal tree



^ Live tree

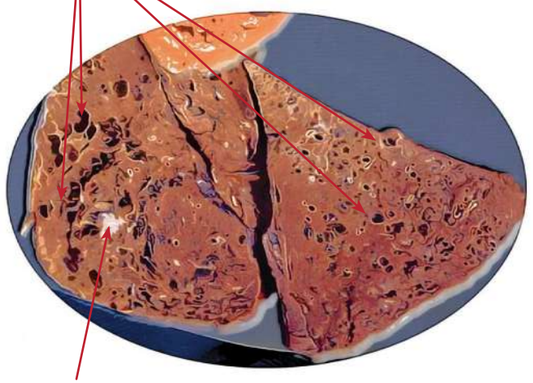
v CG tree

Medicine

Modern medical equipment (MRI and tomography) allow you to obtain a huge amount of digital data about the internal organs of a patient. The computer performs a mathematical analysis of this data and identifies fractal structures. Cancerous tumors and emphysema have a more complex structure, while healthy areas are simple. The principle of self-similarity in a fractal allows us to reveal deviations in the very earliest stages and do so automatically, without the participation of a doctor.

Emphysema

v A model of fractal analysis in the diagnosis of lung cancer

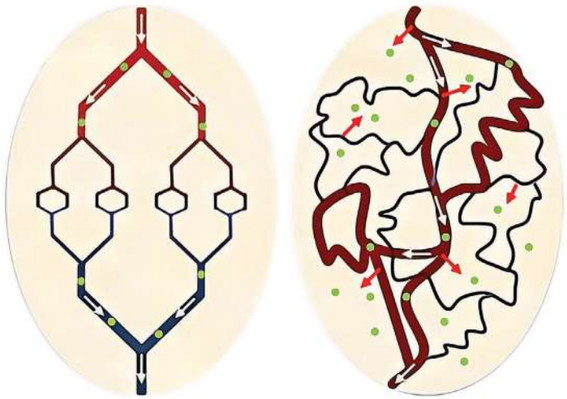


Lung cancer

Cancerous tumors are made through the anomalous, rapid growth of cells, which are accompanied by the formation of new and disordered blood vessels. Healthy blood vessels have an ordered fractal structure.

< Normal vasculature

> Tumor vasculature

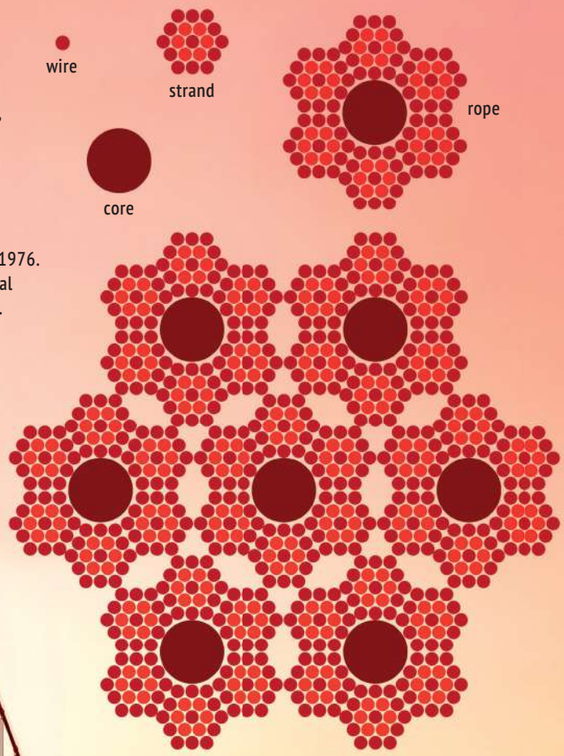


Construction

Modern engineers use high-tech cables, which are woven according to the fractal principle (a cable is formed from a bundle of cables, which are, in turn, formed from smaller wires, and so on).

The Golden Gate Bridge in San Francisco is one example in which such technology was used.

< Strands of History, 1936–1976. Golden Gate Bridge original suspender cable. Souvenir.



^ Cross section of the Golden Gate Bridge's cable

ANTIMATTER

This term is often found in science fiction because authors love to attribute the most unbelievable properties to this mysterious substance. But what does science know about it? First of all, antimatter actually exists. Secondly, there is very little of it. And thirdly, it can shed light on the laws under which our universe exists.

In the Beginning, There Was an Idea

It all started with the idea of **antigravity**. In the 1880s, British physicist and mathematician William Hicks (don't mix him up with Peter Higgs!) was considering the vortex theory of gravity. According to this theory, the attraction between bodies arises from vortices of aether which penetrate space. Hicks proposed that a substance with negative gravity exists. Another British physicist, Sir Arthur Schuster, reduced this idea to the term **"antimatter,"** which he used in a letter published in the journal *Nature* in 1898. He also conjectured that when matter and antimatter meet, their equivalent quantities should disappear, turn into nothing, and **annihilate** one another (from the Latin *nihil*, for "nothing"). The idea was not entirely correct. It should be noted that, at that time, the scientific community had not yet fully adopted the concept of atoms and molecules. Although, in 1897, yet another British physicist, J.J. Thomson, discovered the electron. Fast-forwarding, we can now say that antimatter does not possess antigravity, but it does know how to annihilate.

Physicists decidedly liked these terms, so they coined them as a way to describe these hypothetical phenomena. The beginning of the 20th century was a time of rapid development in physics: quantum mechanics, wave-particle duality, and other daunting ideas came into the world.

How Dirac Came to Discover the Antiworld

Consider Dirac's simplified relativistic equation for an electron.

$$E^2 = m_0^2c^4 + p^2c^2$$

(energy; speed of light; mass of a particle at rest; particle momentum)

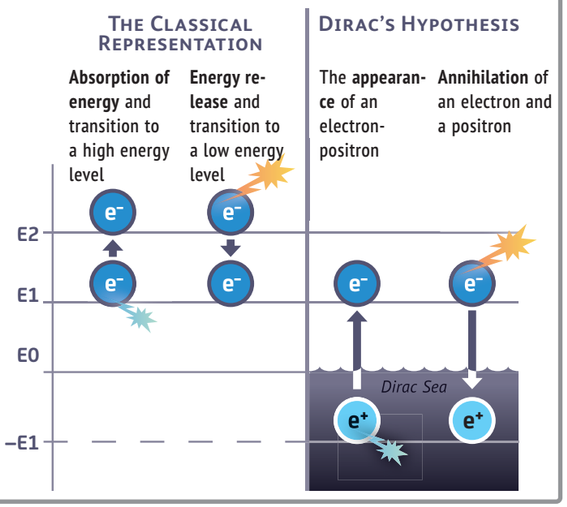
$$E = \pm\sqrt{m_0^2c^4 + p^2c^2}$$

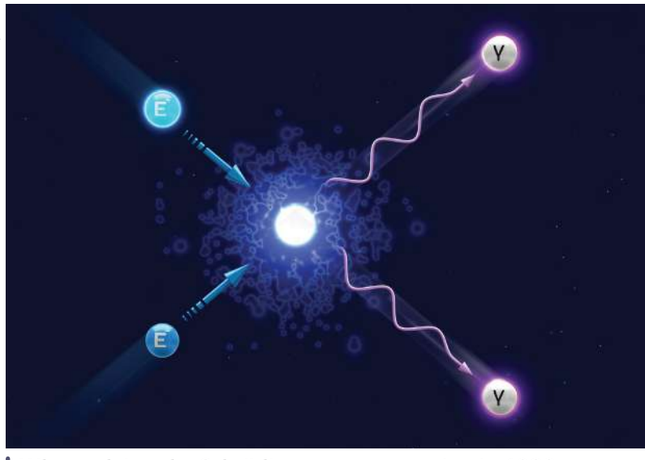
This equation for calculating energy has two solutions: negative and positive. But the negative value was discarded as impossible because, as energy changes continuously, it cannot change its sign. But Dirac set out to explain and interpret the **physical meaning of negative energy**. In quantum theory, unlike classical theory, changes in energy occur *intermittently*.

Dirac suggested that the negative energy levels are already filled with some kind of *invisible* particles (called the **Dirac sea**). Suppose that we transfer energy to one of these particles. According to our expectations, it should move to a higher energy level in the positive area, where we will see it as an electron. At the particle's place in the negative zone, a "hole" is formed. Because there was a negative particle (an electron) here before, the hole must acquire a positive charge exactly equal to the charge of the electron. After all, before we transferred energy to an *invisible* particle, it had a neutral charge (otherwise, it would be *visible*).

Why can't this hole be occupied by another invisible particle? Because of the **Pauli exclusion principle**, according to which there cannot be more than one electron in one quantum state at the same time. That is, **each hole has one electron**. Furthermore, Dirac suggested that, most likely, this is not just a fragment of emptiness, but a positive electron, or a **positron**. The Dirac model explains why the particles appear in pairs (particle-antiparticle), and energy is released when they are annihilated.

This theory was met with skepticism. It could only be proven through experimentation. They had to either find this particle or disprove the hypothesis.





As a result of the annihilation of an electron and a positron, gamma quanta photons are formed. In the most common case, this is two photons, each of which possesses energy equal to the resting energy of an electron or positron (0.511 MeV).

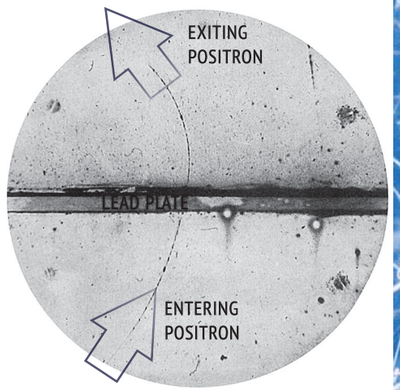
When solving the Schrödinger wave equation in 1928, one of the greatest physicists in history, Englishman Paul Dirac, predicted that an electron should have a counterpart similar in mass but opposite in charge.

An Above-Ground Discovery

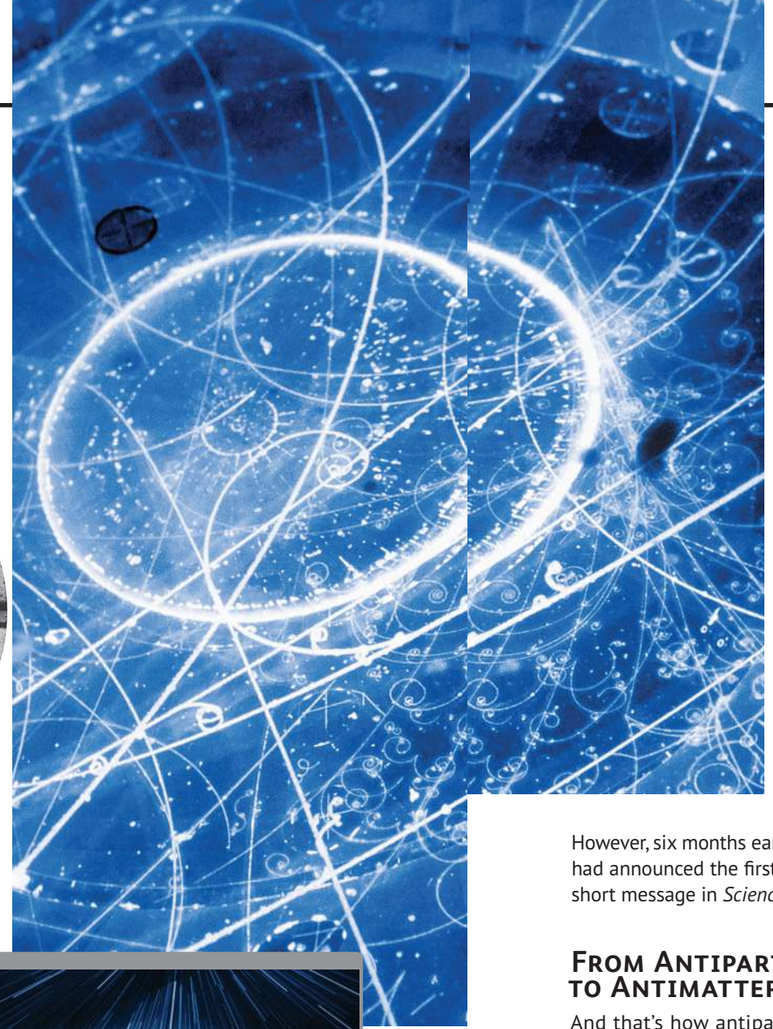
The discovery of antimatter did not take place entirely on Earth. In 1932, a young American physicist, **Carl Anderson**, set up a series of experiments on the study of cosmic rays in a **cloud chamber**.

Based on the deviation of the particle trajectory in the chamber, it was clear that this particle was the carrier of a single positive charge. At first, everyone thought about the good old proton. But the proton has a much larger **ionization potential** (the ratio of the energy needed to detach the particle from its charge); that is, a much larger mass. This value, by magnitude, coincided with the value of an electron. From all appearances, the mass of the unusual particle was approximately equal to that of an electron.

But there was still the possibility that these were not positively charged particles but only electrons that changed direction as a result of scattering. To rule out this possibility and trace the direction of the particle's motion, Anderson developed an elegant experiment: he placed a ¼-inch lead plate parallel to the Earth in a chamber. Now the particle, passing through it, should have reduced its energy and changed accordingly with the curvature of the trajectory. There was nothing left to do but to recognize that "positively-charged electrons" originate in space. The scientist called this particle a "positron" (from *"positive electron"*) and proposed changing the name of the electron to "negatron," by analogy with the positron. Anderson's article was published on March 15, 1933, in the journal *Physical Review*.

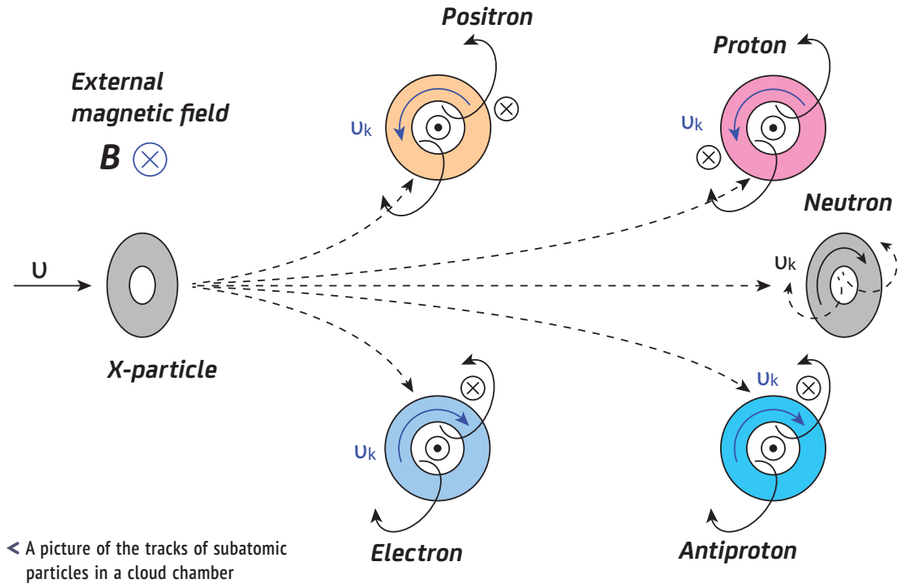


∧ Trace of the trajectory of a positron in the Wilson cloud chamber from Anderson's 1932 experiment. The particle loses a part of its energy when passing through the lead plate and rotates in the magnetic field.

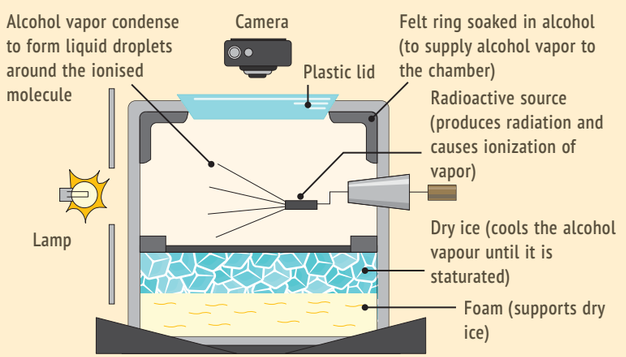


< A picture of the tracks of subatomic particles in a cloud chamber

Movement of particles in a magnetic field



The **Wilson cloud chamber** is one of the first instruments in history designed to record the tracks of charged particles. It was named after its inventor, Scottish physicist **Charles Wilson**. In the chamber, a supersaturated vapor is created, through which a stream of charged particles is passed. The particles leave ions behind them, which causes the vapor to condense. The user then photographs the condensate formed along the trajectory of the particle.



Cosmic rays are a stream of elementary particles and nuclei of atoms moving with high energies in outer space. They were discovered by the Austrian physicist **Victor Franz Hess**, who launched his measurement instruments in a balloon and observed that at altitude, the ionization level of the air is higher and remains the same day and night. The baton was then passed to the american scientist **Robert A. Milliken**, who, following the advice of the soviet physicist **Dmitri Skobeltsyn**, adapted Wilson's camera to study the tracks of cosmic ray particles. His student, **Carl Anderson**, conducted research with a cloud chamber on mountain peaks and in hot air balloons.

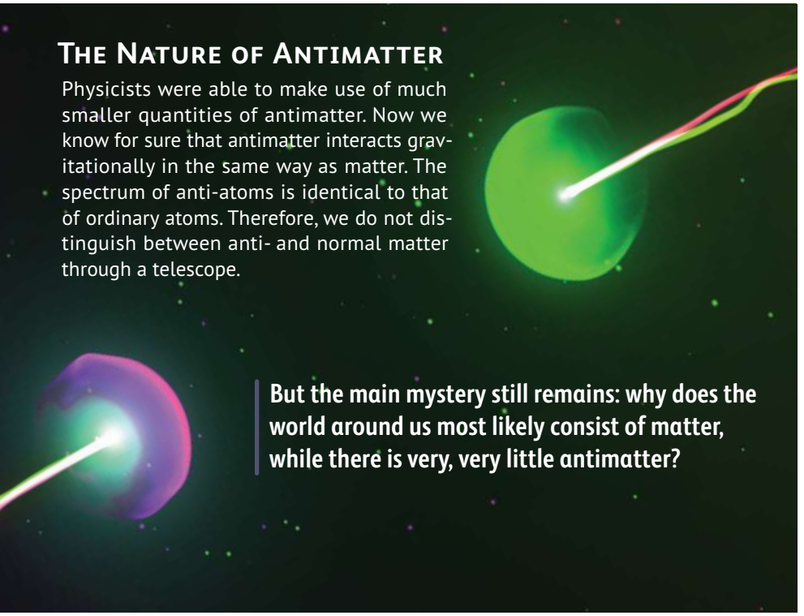
However, six months earlier, the physicist had announced the first antiparticle in a short message in *Science* magazine.

From Antiparticles to Antimatter

And that's how antiparticles were discovered. Well, more precisely, how one of them was discovered. In 1955, **Emilio Gino Segrè** and **Owen Chamberlain** discovered the **antiproton**, winning a Nobel Prize for their work along the way. A year later, **Bruce Cork** and his colleagues discovered the **antineutron**, and it thus became possible to study antimatter.

In principle, the antiproton was already the core of antihydrogen, but something was missing. In 1965, an *antideuteron*—a hybrid of an antiproton and an antineutron—was obtained. In the 1970s, antitritium and antihelium nuclei were discovered in Serpukhov, USSR (present-day Russia). Only in 1995 CERN physicists were able to "assemble" an antihydrogen atom. But at that time, they were separate atoms.

A real breakthrough in the study of antimatter was achieved in the 2010s. Thirty-thousand antiprotons, cooled down to – 99.4˚F, and 2 million positrons, chilled to –387.4˚ F, yielded 38 antihydrogen atoms that lived for 172 milliseconds. A year later, 309 atoms were created, and they existed for 1000 seconds!



The Nature of Antimatter

Physicists were able to make use of much smaller quantities of antimatter. Now we know for sure that antimatter interacts gravitationally in the same way as matter. The spectrum of anti-atoms is identical to that of ordinary atoms. Therefore, we do not distinguish between anti- and normal matter through a telescope.

But the main mystery still remains: why does the world around us most likely consist of matter, while there is very, very little antimatter?

In accelerator experiments, particles are produced only in pairs: an antiparticle and a particle. The same thing probably happened at the time of the Big Bang — an equal number of particles and antiparticles appeared. But in that case, all matter would have been annihilated and the universe would consist of radiation alone. The paradox of the so-called **Baryon asymmetry** (cases in which there is matter but no antimatter) remains unresolved.

One of the most prominent versions of the paradox is the **violation of CP symmetry**. What is this? For a long time, it was believed that if all particles were simultaneously replaced by antiparticles and a mirror image of the physical system was made, then the laws of physics would not "notice" the inversion; everything would remain the same. This is CP invariance. What emerged from it is that there is no difference between particles and antiparticles, including the way they come into existence.

However, in the 1960s, two American physicists proved that invariance is violated in some instances.

The Fermi Gamma-ray Space Telescope (FGST) is a gamma-ray astronomy observatory in low Earth orbit, used to observe high-energy spikes in space, for example, in galactic nuclei and pulsars

25 MILLION DOLLARS

That is how much the production of a *approximately 3.5 oz* of positrons, the simplest variety of antimatter, costs. This makes antimatter the most expensive substance on Earth, and it is also extremely difficult to maintain.

James Cronin and Val Fitch won the Nobel Prize for demonstrating that invariance is violated during the disintegration of **neutral kaon**. Their experiments exhibited that this violation is not sufficient to obtain the required amount of a substance, because reactions going backward in time are not identical to those going forward.

It has also been suspected that dark matter consists of antimatter. But, in that case, gamma-telescopes should register signals from its annihilation. The results of a 413-week observation session of the Fermi Gamma-ray Space Telescope were recently published, but there was nothing suspicious!

On a daily basis, the same telescope observes the birth of large amounts of antimatter on Earth.

In 2011, Fermi recorded gamma-flares caused by the annihilation of positrons produced in the air by ordinary lightning. Powerful lightning, as it turned out, can produce up to 100 trillion positrons.

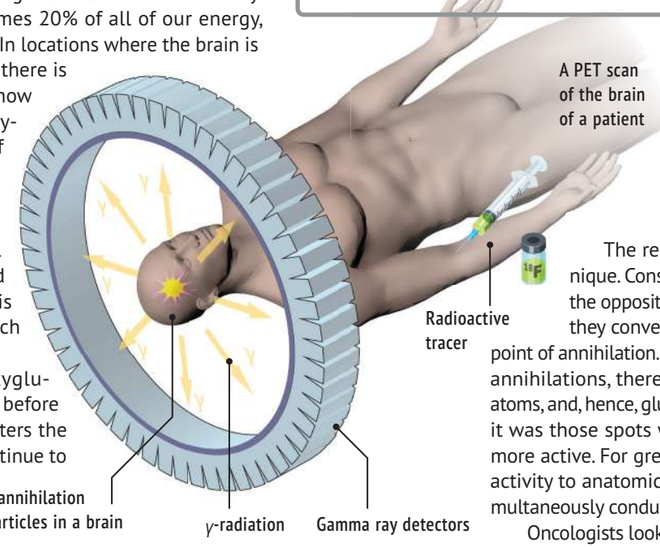
Antimatter at the Service of Humankind

But most interestingly, antimatter has been at humankind's service for four decades. During certain medical research on the human body, annihilation takes place.

One example of this stems from our need to see the activity of brain regions in real-time. What is required to accomplish this? One cyclotron, one chemical laboratory, and a positron emission tomography, or **PET scanner**, the first versions of which were created back in the 1970s.

Our brain, although it only weighs 1.5–2% of our total body weight, is voracious and consumes 20% of all of our energy, generally in the form of glucose. In locations where the brain is more active at a given moment, there is more glucose in the blood. But how can we see it? It's simple. In a cyclotron, you develop an isotope of fluorine ^{18}F, the half-life of which is 109.8 minutes. This isotope exhibits beta plus decay, which emits a positron. Next, a typical glucose molecule is taken and one of the hydroxyl groups in it is replaced by a fluorine atom, which is close in size.

This makes 18-fluorodeoxyglucose, and you drink this solution before undergoing the test. Glucose enters the brain and the fluorine atoms continue to disintegrate.



That is to say, positrons are being born right inside our brains. They don't get very far, though: after moving just a few fractions of an inch, annihilation occurs. The positron disappears, and two gamma quanta shoot out in opposite directions, before being "caught" by the sensors in the ring of the scanner.

The rest is a matter of technique. Construct straight lines in the opposite direction and, where they converge, you will "see" the point of annihilation. Where there are more annihilations, there were more fluorine atoms, and, hence, glucose. This means that it was those spots where the brain was more active. For greater accuracy, linking activity to anatomical details, you can simultaneously conduct an MRI or CT scan.

Oncologists look for metastases in the same way, but instead of fluorinated glucose, they use radiopharmaceuticals that locate cancerous tumors with great precision. So antimatter is, of course, still the stuff of fantasy, but at the same time, it is a reality that saves many lives every year.

AN ANTIMATTER BOMB

In Dan Brown's novel *Angels and Demons*, villains steal a gram (about 0.035 oz) of antimatter from CERN and threaten to blow up Rome. Now we know that when a substance meets antimatter, both masses disappear, turning into radiation strictly according to Einstein's formula: $E = mc^2$. As you can see, there is a monstrous magnitude in this formula — approximately 671,080,888 mph, which is roughly equal to the speed of light. This makes antimatter much more powerful than a thermonuclear bomb. Calculations show that the annihilation of that stolen gram of antimatter would have been equivalent to around 474,000 t of TNT!

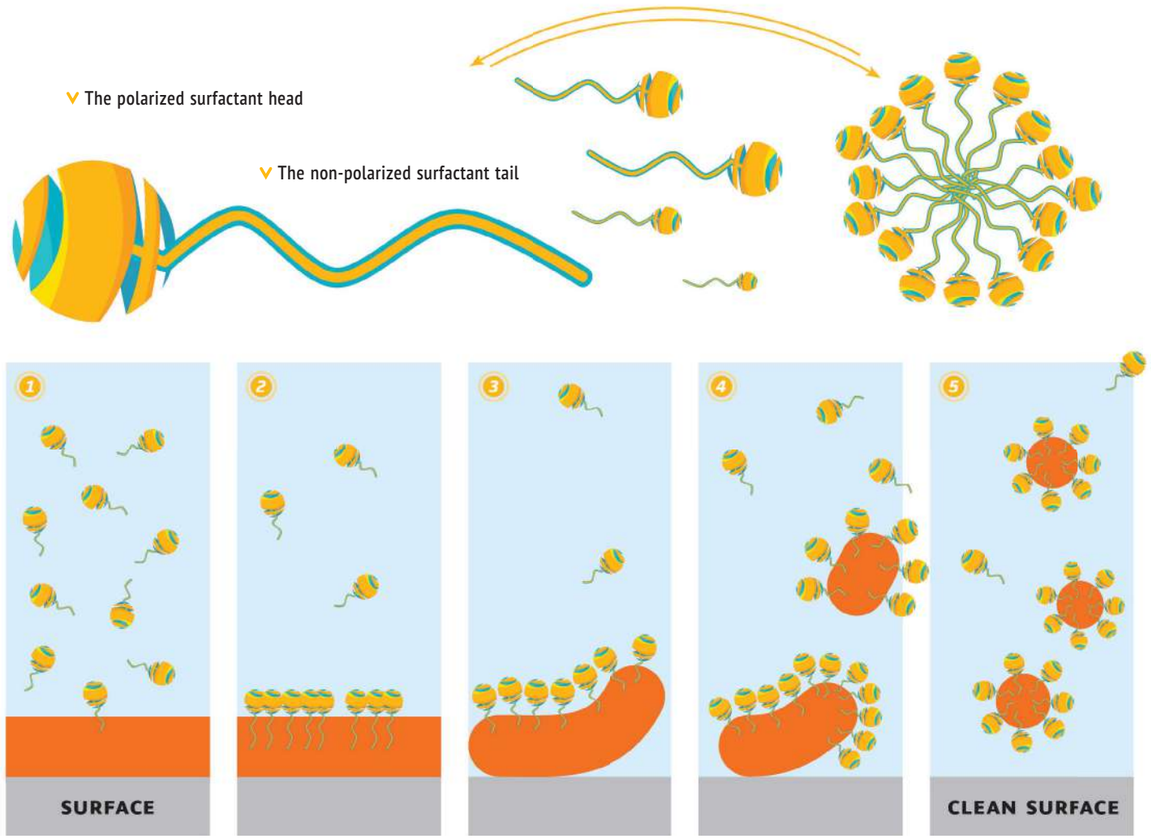
SUDSY SOAP
and Other Surfactants

Every day, more than 6.5 lbs of these substances are produced per inhabitant of the Earth. No, we're not talking about food products. We mean compounds that reduce the surface tension of liquids.

Heaven-Sent Cleanliness

Soap can arguably be considered the most popular **surfactant**. Sodium or potassium salts of fatty acids make up the core of the cleansing agent, and they have a complex structure. The molecule of such acids is "bilateral": one half repels water (**hydrophobic**), and the other is attracted to it (**hydrophilic**). When you soap up your hands, the hydrophobic parts of the molecules come into operation, moistening the grease. When we put our hands in water, the hydrophilic side comes into play — it attaches itself to the water and carries away the whole molecule, along with harmful substances and bacteria, into the sewer system. If you simply rinse your hands with water, the fatty particles and the contaminants they have accumulated will remain on your skin.

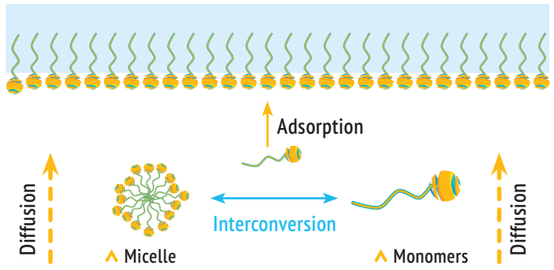
How Does Soap Work?



Soap dissolves in water — Surfactant ions orientate themselves in grease and water — Agitation begins to separate grease from surface — Process continues — Cleaning complete

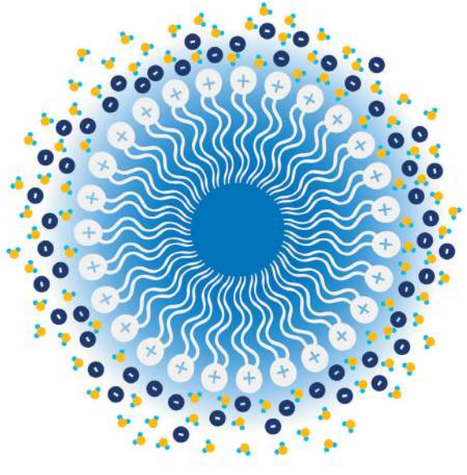
The hydrophobic part of the molecule is active in all non-polar solvents, such as gasoline or oil, so soap is well-suited for the removal of such contaminants. It is interesting that surfactants can work only at the interface between two states: liquid-gas, liquid-solid, or two immiscible liquids. They look for boundaries between states, just like spies, and this is why substances that reduce surface tension are called **surfactants**, or **"surface-active agents."** The surfactants have mastered an entire procedure for transit from the liquid solution to the state interface — **adsorption**, the essence of which lies in the accumulation of substances in the surface layer. Surfactant molecules are able to independently move to the interface of two substances.

If there are too many surfactants, more than the boundary can hold, the molecules gather into microscopic spherical

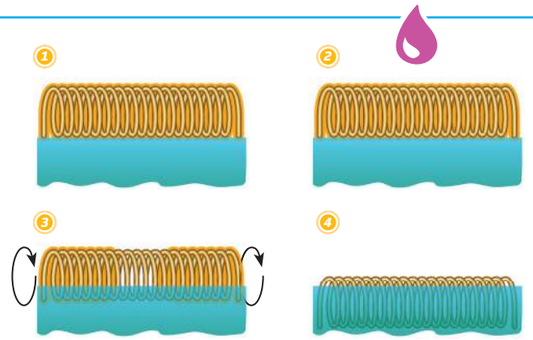


droplets of **micelles** (from the Latin "micella," meaning a small particle).

The micelle is a sphere of molecules with protruding hydrophilic ends and a diameter of a few nanometers.



Acquiring a micellar solution is simple: to make it, pour a thin stream of liquid soap into water until it becomes cloudy. Such a solution with microparticles of liquid soap, capable of wetting many surfaces, is called a **colloidal solution**. By the way, milk and blood also belong to the category of colloidal solutions.



Demonstration of the Work of Surfactants

Take a thin copper wire, wrap it a few times into a spiral, and lightly grease it with vegetable oil. Gently place it on the surface of the water. Due to the low weight and hydrophobic fat, the copper wire does not sink. Now for the main act — drip liquid soap from a pipette into the center of the spiral. The copper wire will start spinning and then sink! Soap, merely by means of its presence, enables water to moisten the fat, and the difference in surface tension on different parts of the wire makes it rotate, and eventually the wire sinks. **The stronger the surfactant, the faster the rotation**.

Different Surfactants are Necessary

Ninety-nine percent of all surfactants are organic substances — alcohols, fatty acids, and their salts, as well as other compounds based on carbon and hydrogen. According to the stories of the ancient Roman writer **Pliny the Elder**, people were able to use such compounds as surfactants even before the common era. To do so, they mixed wood ash from beech with goat fat, and voila! The first soap was created. Later, alchemists thought up the idea of treating natural oils with sulfuric acid, and the French scientist **Edmond Frémy** prepared detergents from olive and almond oils in 1831.

In Germany in 1843, people added coconut oil to their cooking pots for soap. At first, though, the aromatic soap did not sell very well.

The new product did not have the familiar unpleasant smell of rancid fat, which people had grown used to, so they thought the coconut soap to be low-quality.

A Daily Chemical

SODIUM LAURYL SULFATE

White powder

$CH_3(CH_2)_{11}OSO_3Na$

Sodium lauryl sulfate (also known as sodium dodecyl sulfate or SLS) is a surfactant present in many cleaning products such as toothpaste, shampoo, shaving foam, and bath foam.

In shampoo

Sodium lauryl sulfate is a surfactant, the molecule of which contains both a water-soluble and water-insoluble part. It attaches to grease or dirt and tends to dissolve in water. This substance also reduces the surface tension of water and forms bubbles.

In toothpaste

SLS is added to the paste as a foaming agent. It also irritates the taste buds in the mouth. This substance suppresses taste buds and destroys phospholipids, which act as inhibitors of acute stimuli receptors. Drinking orange juice after brushing your teeth will seem unpleasant to you since SLS dulls your taste buds and strengthens the juice's bitter aftertaste.

Engine degreaser

Sodium lauryl sulfate is present in some engine degreasing agents. The substance is present in such degreasers in a much larger amount than in shampoos, for example. They are also used by various industries as a leather softener, wool cleanser, and floor cleaner.

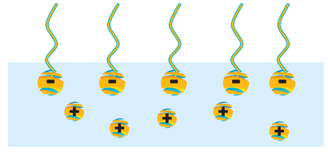
Potential protection from sharks

Studies conducted in 2001 showed that sodium lauryl sulfate exhibits shark-repellant properties due to its hydrophobic nature. However, despite this potential application, the substance is not used as a primary means of protection against shark attacks. Semiochemicals, as well as defensive toxins of marine organisms, were proposed as alternative repellent agents.

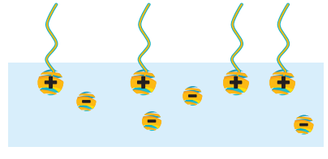
Modern surfactants are divided into ionic and non-ionic. They are distinguished by their behavior in aqueous solutions; ionic surfactants become ions when dissolved. Both positive charge ions (cations) and negative charge (anions) can display surface activity. They are called cationic and anionic, respectively. Cationic surfactants are organic bases with salts, while anionic ones are organic acids with salts.

Ionic Surfactants

Anionic



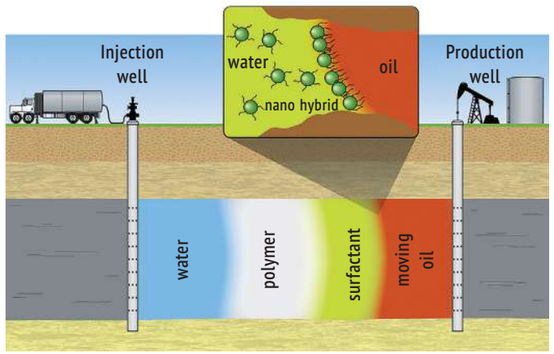
Cationic



Amphoteric surfactants are the sort of *"Dr. Jekkyl and Mr. Hyde"* among ionic substances because they are able to manifest both as cationic in acidic solutions and as anionic substances in alkaline solutions. Non-ionic substances do not decompose into ions in water, but they dissolve perfectly due to the formation of a hydrogen bond between the H_20 molecule and the functional group of surfactants. Such surfactants appeared relatively recently, in Germany in the 1930s, but they already hold a steady position in the world in terms of production volume, second only to anionic surfactants.

Instructions for Use

Detergents such as soaps, washing powders, and shampoos account for almost half of the global production of surfactants. Workers in the oil industry add surfactants to water-oil emulsions to quickly get rid of impurities in the water, as well as to improve oil recovery from underground reservoirs.



We also need surfactants to mix liquids that do not want to be in the same solution, for example, oil lubricating mixtures. Surfactants are used to produce nano-objects in the process of liquid dispersion (grinding of solid bodies) and emulsification (mixing of two or more liquids that are normally immiscible).

In metalworking processes, surfactants are used as cutting fluids that reduce friction and simplify cutting and milling.

A SCALY ANCESTOR

Toothy, dark blue, 5 feet in length, covered in scales, and even with legs. Have you guessed who this is? None other than our shared great-grandmother! Of course, coelacanths, or the genus *Latimeria*, are not our direct ancestors, but they are still relatives of beings that first left the seas 385 million years ago and became four-legged terrestrial animals, from which we sprung. And these relatives are still alive today!

Old Fourlegs

On December 22, 1938, floating off the South African coast in the Indian Ocean, fishermen from the Irvin & Jones Company caught an unknown creature. It weighed 188.5 lbs, was about 5 ft in length, dark blue in color, and unabashedly chomped its jaws. This was not just any fish — it had scales, fins, and…limbs. Or, more precisely, rudiments thereof. Moreover, there were seven of them: two on the back, three on the belly, and another pair on the head.

It should be noted that the local population occasionally caught these creatures and had even come up with a name for them, *gombessa*, which can be translated as "bitter fish." The residents knew that it was nearly inedible (it was consumed due to the belief that its meat helped to cope with malaria symptoms), although it was possible to make something like sandpaper from their extremely strong and bristly scales. So for the local fishermen, perhaps, it was not such a curiosity; nevertheless, they called the curator of the local East London Museum, **Marjorie Courtenay-Latimer.** The museum had a standing arrangement with the fishermen, requesting that they report all unusual findings.

< Ms. Courtenay-Latimer and the fish she discovered

* *Photo: The South African Institute for Aquatic Biodiversity*

Ms. Courtenay-Latimer was an ordinary museum worker, but after a single glance at the creature, she immediately realized that there was something unique in front of her. The animal was like a bridge between a fish and a lizard. She looked through the records and could not find anything similar. Meanwhile, she needed to work quickly — the fish was decomposing in the African heat right in front of her.

Ms. Courtenay-Latimer had a hard time persuading a local taxi driver to take the decaying carcass to the museum or to even let her drag it into the car. And then, she had to listen to **Dr. Bruce Beis**, the Chairman of the museum, mocking her: "To you, all ugly ducklings seem to be swans."

Nevertheless, she sent the fish to a taxidermist, sketched an approximate picture of the find, and sent for her friend, ichthyologist **J. L. B. Smith**, who was in a different city at the time.

> **Smith, who later wrote a book about the fish they discovered, called *Old Fourlegs: The Story of the Coelacanth*, described his feelings upon reading the letter from Ms. Courtenay-Latimer:** "And then a bomb seemed to burst in my brain, and beyond that sketch and the paper of the letter, I was looking at a series of fishy creatures that flashed up as on a screen, fishes no longer here, fishes that lived in dim past ages gone, and of which only fragmentary remains in rocks are known. I told myself sternly not to be a fool, but there was something about the sketch that seized on my imagination and told me that this was something far beyond the usual run of fishes in our seas…"

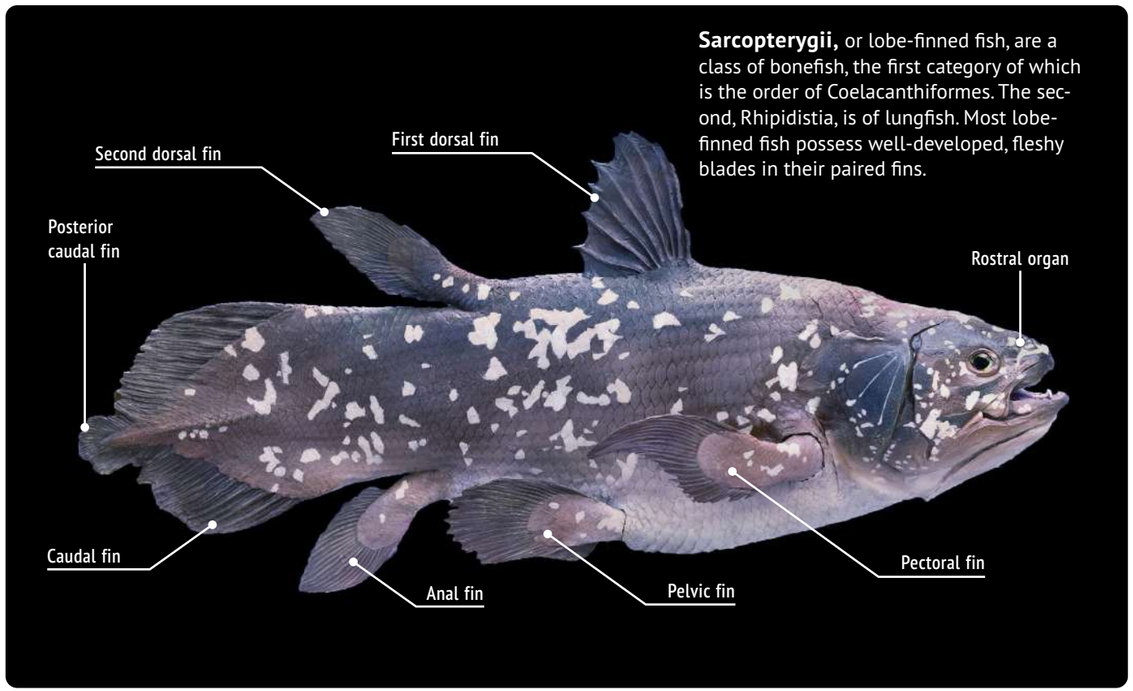
But that "burst" happened not only in Smith's brain. At that time, the entire scientific world waited with bated breath. It turned out that the scientists had something more extraordinary on their hands than a dinosaur — it was a living ancestor, believed to have died out about 70 million years ago. In honor of Marjorie Courtenay-Latimer, Smith named the fish *Latimeria*.

Previously, species of *Latimeria* were called brushfishes, but this term has since become obsolete. A specimen discovered in South Africa was named *Latimeria chalumnae*, and in 1997–1999, a second species (which was brown in colour), *Latimeria menadoensis*, was discovered and described near the island of Sulawesi in Indonesia. All other species of Coelacanthiformes are now thought to be extinct.

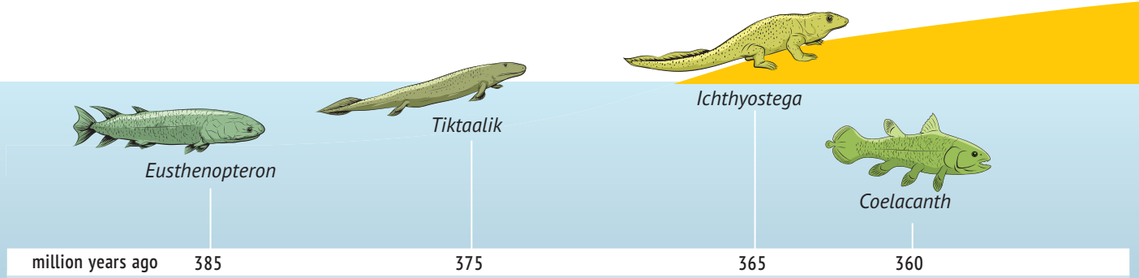
Our Cousin's Grandpa

This fish is, of course, not our direct ancestor. Terrestrial vertebrates (also called tetrapods), to which we belong, are closer to the lungfish, an ancient group of fish possessing both lungs and gills. Nevertheless, both the coelacanth and the lungfish come from the same ancestor, and both belong to the same class of lobe-finned fish. Therefore, the "zoological sensation of the 20th century" (as *Latimeria* was christened) can be considered our distant relative.

Since the birth of the lobe-finned fish 400 million years ago, it has changed, albeit not too dramatically: its size has increased, its swim bladder is filled not with air but with fat, and the proportions of its body have been modified. Nonetheless, *Latimeria* resembles our distant forefathers. It does not have a spine but instead something like a chord, a flexible elastic rod running along its back, which was the predecessor of our bodies. Also, it has a small appendage at the end of its body, similar to the embryo of the tails seen in amphibians. But most importantly, the coelacanth has the rudiments of limbs, the very ones that helped our ancestors to climb out from the sea onto dry land.



Sarcopterygii, or lobe-finned fish, are a class of bonefish, the first category of which is the order of Coelacanthiformes. The second, Rhipidistia, is of lungfish. Most lobe-finned fish possess well-developed, fleshy blades in their paired fins.



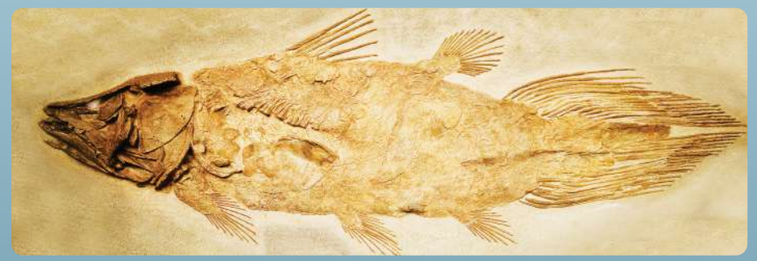
In addition to the class of lobe-finned fish, there is the famous *Tiktaalik*, a more "advanced" species than *Latimeria*, which lived 375 million years ago and was a transitional form between fish and amphibians. It, too, was probably not our direct ancestor. Around 385–375 million years ago, many "fleshy-footed" beings began to find themselves on land, just like *Tiktaalik*. There were many reasons for this: from the large number of arthropods who floated along the banks of rivers and lakes, to the increasing threat of predators, to the eutrophication of small bodies of water — in those distant times, there were not enough decomposers, like fungi and bacteria, to process dead vegetation and animals, meaning that they died in the water and stayed there for a very long time, making the space very cramped.

Deeper and Colder

The coelacanth is a tropical fish, but that does not mean that it loves sunlight and heat. On the contrary, this fish prefers the depths (from 650 to 2,300 ft) and surfaces to a level of 250-330 ft only at night.

Coelacanths are predators (again, look at those teeth!). Their diet includes fish and even small sharks. Most of the coelacanth's meals live in underwater crevices and caves, where the fish prefers to swim. The animal's mouth structure allows it to move not only the lower jaw but also the upper one, enabling it to efficiently suck in food.

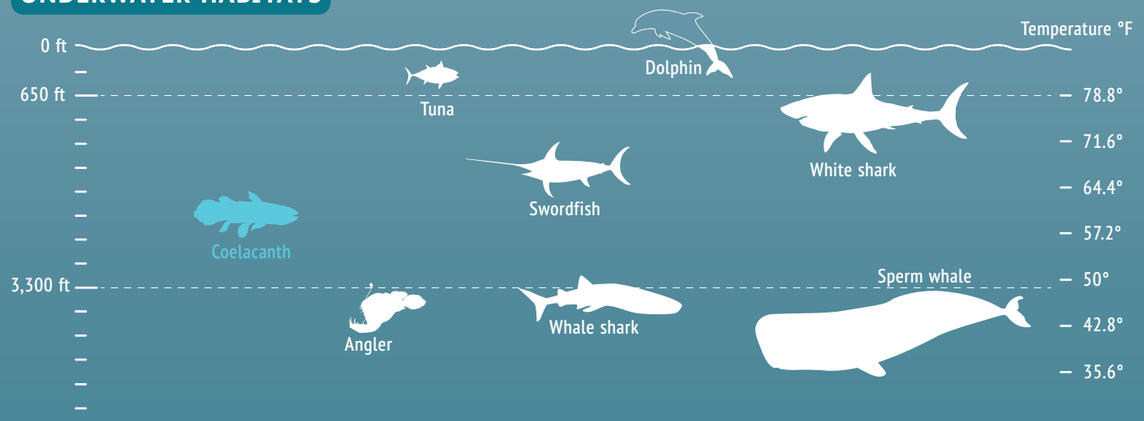
The coelacanth can turn upside down and hang in this position for up to two minutes. Scientists have found that, in this way, the fish detects weak electric fields, caused by contact between living tissues and water at the bottom of the ocean. To do so, Old Fourlegs has special organs called electro-receptors.



Interestingly, the fin movement of the *Latimeria* is similar to that of the extremities of most terrestrial vertebrates: first, the fish simultaneously moves the left thoracic and right ventral fins, and then the right thoracic and left abdominal simultaneously as well.

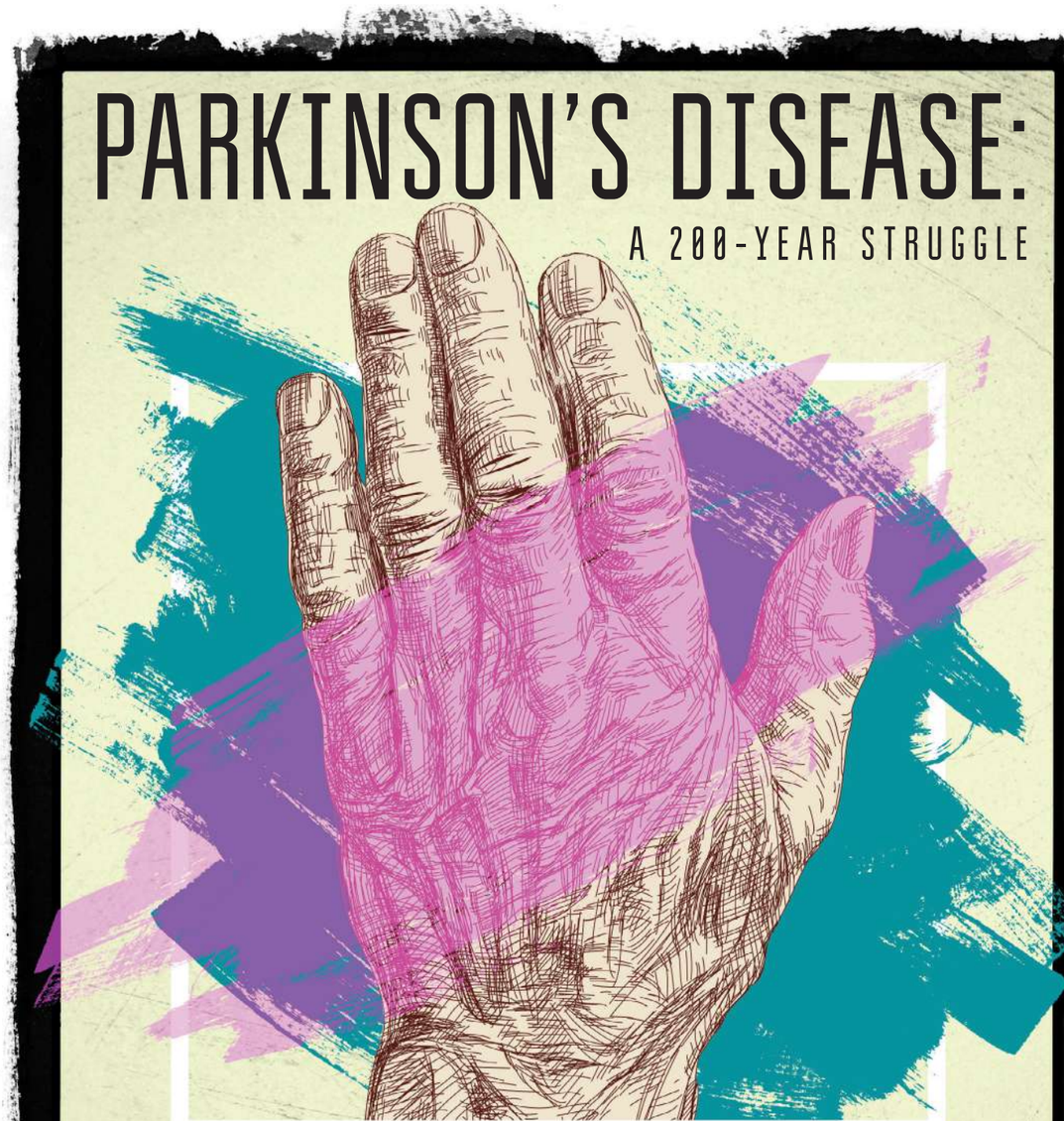
Coelacanths have very long lifespans. They can live to see their 80th and even 100th birthday. They are also ovoviviparous, which means that they do not spawn like most fish that we know, and they do not lay eggs like lizards. Instead, they carry the eggs inside themselves. Thirteen months after conception (yes, *Latimeria* pregnancies last even longer than in humans), the young hatch from their eggs.

UNDERWATER HABITATS



PARKINSON'S DISEASE:

A 200-YEAR STRUGGLE



To this day, we do not fully understand how and why it arises or how to treat it. We can only relieve its symptoms—and even for a relatively long time. It spares no one: Mohammed Ali was not the only famous patient with this diagnosis. Pope John Paul II died from complications of Parkinson's disease. The 41st President of the United States of America, George Bush Sr., suffered from this ailment; and the star of the *Back to the Future* trilogy, Michael J. Fox, has struggled with this disease since 1991. And successfully at that: recently, he was able to perform on stage with a guitar!

The Beginning: James Parkinson

Matthew retired not too long ago. Several years ago, he discovered that it became difficult for him to move his hand, and a neurologist came to a tragic conclusion: "You have Parkinson's disease in its initial stages. But don't be upset — we will treat it." From that time on, Matthew read constantly to learn more about his illness. Since he was interested in history, the first thing he discovered was the person after whom the disease was named.

James Parkinson was born on April 11, 1755, in East London to the family of surgeon John Parkinson. He followed in his father's footsteps, becoming a doctor. He was a talented practitioner, saved many people's lives, and even became one of the first members of the Royal Humane Society (a charitable organization which provided first aid to those who were affected by disasters).

Parkinson was observant and noticed many things. This helped him in his scientific research: in 1817, Whittingham and Rowland published his work, "**An Essay on the Shaking Palsy**," in which he summarised six clinical cases.

One of few existing images of James Parkinson (in the center). All of the rest, including photos found on the internet, are falsified. In Parkinson's day, cameras had not yet been invented.

Interestingly, the afflicted were not his patients — as a doctor, Parkinson often walked in the streets of London and observed people with similar symptoms.

It used to be very easy to distinguish this type of patient. First, their posture was hunched, as if they were begging. Secondly, the person's face was practically devoid of facial expression and almost did not show emotions at all. Thirdly, their hands trembled, hence the title of the essay "On the Shaking Palsy." Fourthly, one of the afflicted person's hands was extended forward as if they were counting or rotating something, like money, pills, or prayer beads. Due to muscle spasms, these people moved very little and took small steps, but sometimes, they could set off into a full run — this is called a propulsive gait. It is rare

Symptoms of Parkinson's Disease

Tremor

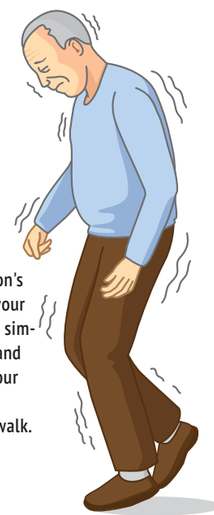
A tremor, or shaking, usually begins in a limb, often your hand or fingers. You may a rub your thumb and forefinger back-and-forth, known as a pill-rolling tremor. Your hand may tremor when it's at rest.

Speech changes

You may speak softly, quickly, slur or hesitate before talking. Your speech may be more of a monotone rather than with the usual inflections.

Slowed movement

Over time, Parkinson's disease may slow your movement, making simple tasks difficult and time-consuming. Your steps may become shorter when you walk.



to see such a vivid picture of the illness now, because patients generally receive maintenance therapy that alleviates many of the symptoms.

Alas, Parkinson's contemporaries did not take note of his work: neurological diseases were not held in great esteem at the beginning of the 19th century. This illness was discovered once more by the "Napoleon of Neuroses," **Jean-Martin Charcot**, who, it seems, had a hand in studying or naming almost all neurological illnesses. Exactly 60 years later, in 1877, he described the "trembling palsy" anew and proposed renaming it **Parkinson's disease** ("*la maladie de Parkinson*").

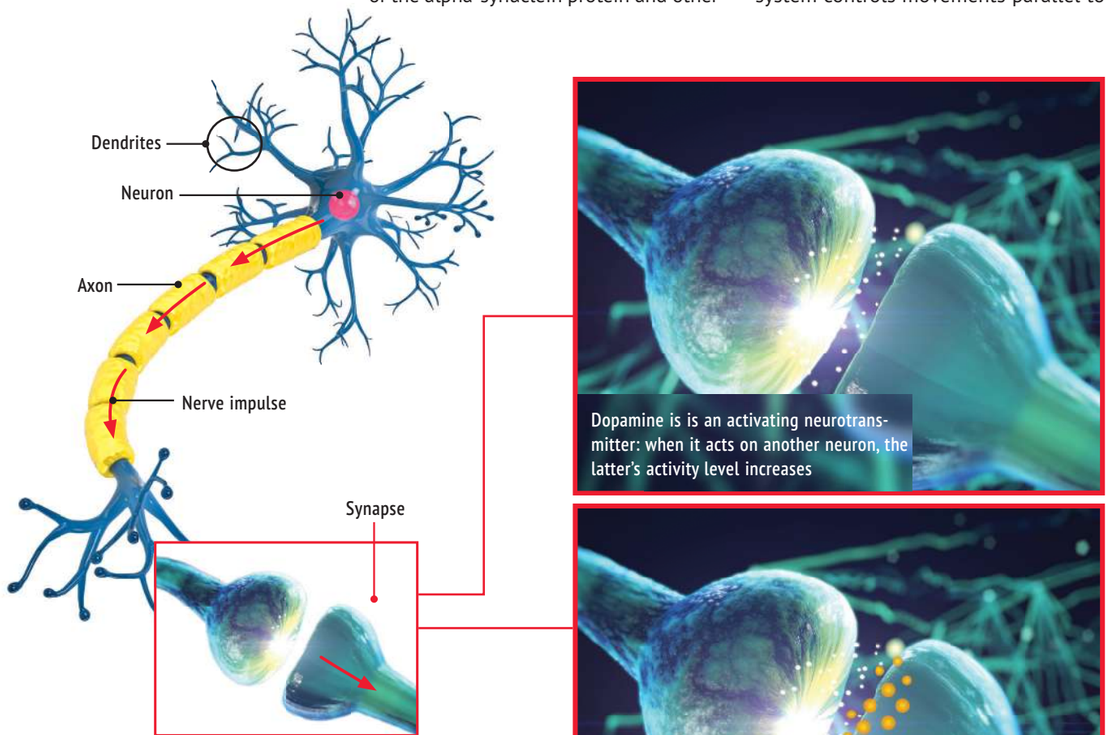
Moving on: What about the Brain?

Matthew did not stop his search, and he spent long winter evenings leafing through books. From a textbook on neurology, he learned that in his illness, clots of foreign matter formed within nerve cells, preventing them from working normally (why this happens is still a mystery). These are called **Lewy bodies**. "Interesting," thought Matthew, as he opened up a search engine in his browser.

It turned out that in 1912, these strange interneuronal bodies were discovered by a German scholar, **Friedrich Heinrich Lewy**. Today, we know that these bodies are made up of components of the alpha-synuclein protein and other proteins, and they are a characteristic sign of **dementia**, the loss of mental abilities.

At this point, Matthew deduced that the symptoms of his illness were caused by the death of nerve cells in the *substantia nigra*. This idea was first proposed by Soviet neuropathologist **Konstantin Tretiakoff**.

Substantia nigra, or "black substance" in Latin, is a part of the human midbrain. This is where neurons responsible for the synthesis of the neurotransmitter **dopamine** are found. If they die, this destroys the neural path through which excitation is passed along to the basal ganglia, as well as the substantia nigra, which is part of the **extrapyramidal system**. This system controls movements parallel to the main motor system (the pyramidal, or corticospinal tract), maintaining muscle tone and coordinating movements. In the case of such a breach, this system is "disinhibited": redundant movements like tremors and other characteristic symptoms appear.

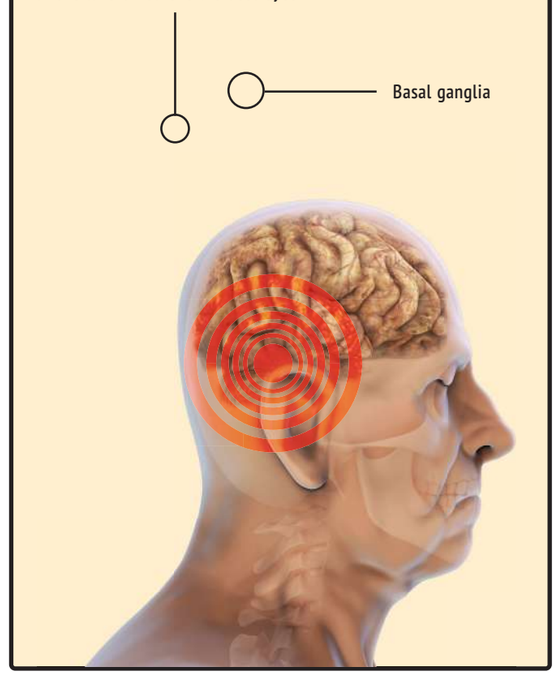


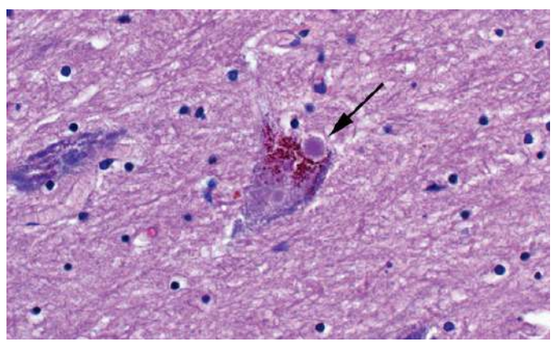
THE MECHANISM OF ACTION OF DOPAMINE

Dopamine is a neurotransmitter that is produced in the human body by special dopaminergic neurons. It transmits information from one cell to another using intercellular contacts, or synapses.

THE PATH OF DOPAMINE TO THE BRAIN

Dopaminergic neurons of the *substantia nigra* use dopamine to transmit signals to the basal ganglia, which controls the movements of an organism, making it active. When these neurons are destroyed (due to the accumulation of Lewy bodies), dopamine becomes short in supply and movement is constrained. Motor activity decreases, and muscle spasms appear.





^ Neurons with pathological accumulations of Lewy bodies (shown by arrows)

Levodopa the Savior

Matthew realized what was happening in his brain. But what did the doctor prescribe him? And how does this medicine help?

Lack of the neurotransmitter **dopamine** plays the primary role in the pathogenesis of Parkinson's disease. Its biochemical precursor is the amino acid tyrosine. The tyrosine enzyme, hydroxylase, uses a "hanging" hydroxyl group (-OH) to convert tyrosine to **levodopa** (L-DOPA). In turn, the L-DOPA-decarboxylase enzyme converts levodopa into dopamine.

Dopamine is not able to pass by itself through the blood-brain barrier — a powerful line of defense and control that prevents all of the things that "float" in our blood from entering into our brains. Therefore, taking it as a medicine is pointless. On the other hand, levodopa passes through perfectly. This promised a bright future in pharmacology.

Levodopa is an abbreviation of L-3,4-dihydroxyphenylalanine, or L-dopa. Matthew learned from a chemistry textbook that levodopa was first synthesized by the Polish chemist **Kazimierz Funk** in 1911 (he also invented the word "vitamin"). This event went unnoticed for a long time, but everything changed dramatically in 1938 when German pharmacologist and physiologist **Peter Holtz** and his collaborators discovered the L-DOPA-decarboxylase enzyme. This allowed us to understand the way that dopamine and other mediators are produced, and put levodopa and dopamine in the group of the most important "informational" molecules of the brain.

Levodopa's fate stirred up curiosity in Matthew and he found out that in the middle of the 20th century, Swedish pharmacologist and future Nobel laureate, **Arvid Karlsson**, set up an experiment: he immobilized guinea pigs with the strongest possible tranquilizer, reserpine, a vegetable poison, and then introduced levodopa to them. They went from lying on the floor with lowered ears to jumping on their feet in practically an instant!

In the early 1960s, Austrian pharmacologist **Dr. Oleh Hornykiewicz** discovered a sharp decrease in dopamine in the basal ganglia of patients suffering from Parkinson's disease. The facts lined up quite logically: dopamine is necessary to maintain the motor activity of the body, and levodopa is its direct biological precursor.

Matthew enthusiastically read about how Hornykiewicz consulted his colleague, Viennese neurologist **Walther Birkmayer**, offering him two grams of levodopa (0.07 oz) for clinical experiments. Intravenous administration of the substance led to a quick, albeit temporary, improvement in the condition of patients suffering from Parkinson's disease. These first experiments allowed for a new era in the history of the illness, making levodopa therapy the gold standard of treatment.

A Strange Cure, but It Works

In addition to levodopa, which in combination with carbidopa is still the only effective drug to treat the disease, there is another method—**deep brain stimulation**, or **DBS**. It helps, but as of now, we're not sure exactly why.

During DBS, long and thin electrodes with a width of only hundredths of an inch are implanted in the brain, pointing towards a target area the size of a corn kernel—the subthalamic nucleus in the basal ganglia. Electrodes gently stimulate it, which eases the motor symptoms of Parkinson's disease.

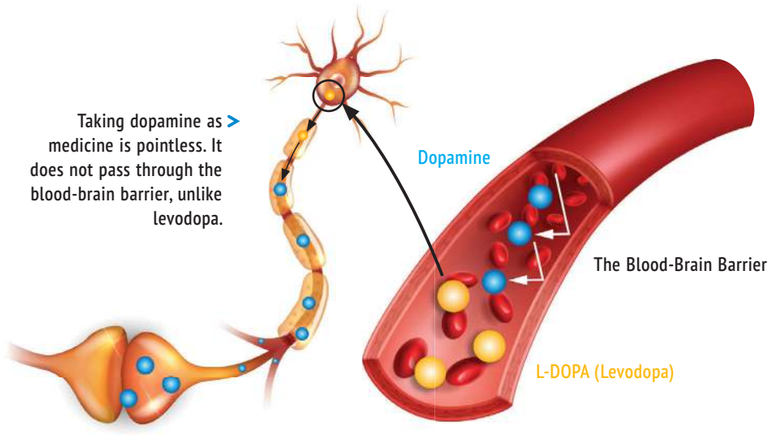
After perusing the internet, Matthew learned that about 10,000 people undergo DBS operations each year for the treatment of Parkinson's. Statistics have already aggregated the results of over 140,000 patients who have used these electrodes. The first DBS operation was performed in 1987 in the French city of Grenoble, and the patient is still alive to this day. It's not surprising that doctors think of this method as something between science, art, and shamanism. But it prolongs life.

New Hope

Matthew was most struck by a piece of information that he stumbled upon by chance: it turns out that if a section of neurons has died, new neurons can be transplanted onto the location! Experiments using this method on macaques have been very successful.

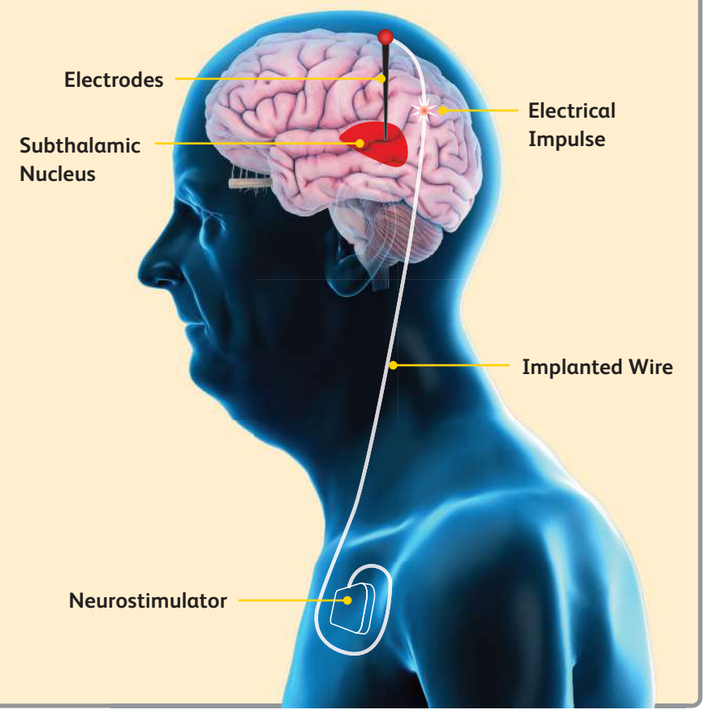
Over the past ten years, cellular technology has made a huge leap, and we no longer need the neurons of donors—we know how to grow our own. This became possible thanks to the work of Japanese scientist **Shinya Yamanaka**, who developed a method for generating stem cells from existing cells in the body, such as skin (which gives rise to all cells in the body). As a result, we now can grow anything from them. Unsurprisingly, Yamanaka was the recipient of the Nobel Prize for Physiology and Medicine in 2012.

A breakthrough in the treatment of Parkinson's also happened in Japan.



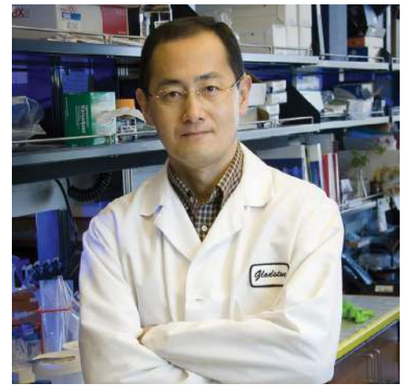
Deep Brain Stimulation (DBS)

This method is used to relieve the symptoms of Parkinson's disease. A small neurostimulator is implanted under the collarbone. The device uses electrodes to send electrical signals to the subthalamic nucleus in the brain, blocking signals with symptoms of the illness. The method does not heal it completely, but it slows down the development of the disease, relieves symptoms, and improves the patient's quality of life.



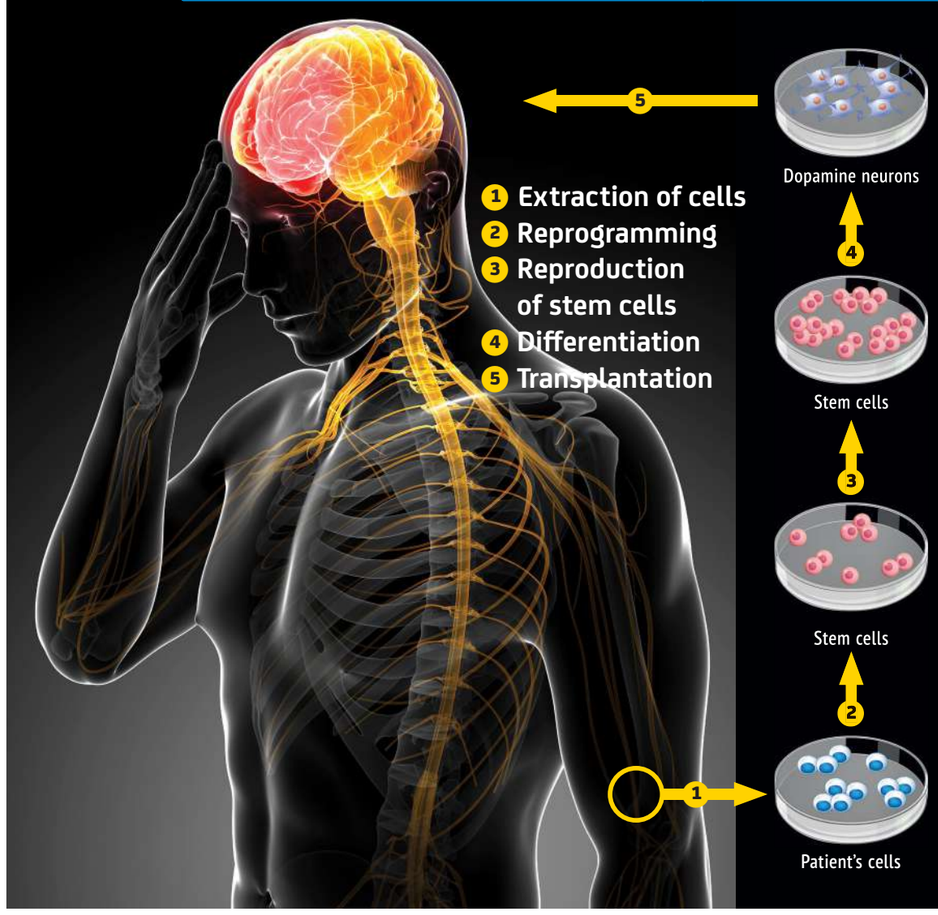
At the end of 2017, a clinical study for a new form of therapy began to recruit participants. Two-year long trials on macaques were successful, so all that was left was to try it on humans. Using the method proposed by Yamanaka, scientists reprogrammed the cells of healthy humans and produced young dopaminergic neurons, which were then implanted onto the brains of macaques with damaged *substantia nigras*. Transplantation of the neurons significantly relieved symptoms of the illness, and the observed effects were long-term: the improvement (without tumor development) lasted for 21 months until the experiment concluded.

Today the whole world, Matthew included, waits anxiously for the results of the experimentation on humans. Parkinson's patients have new hope. And in the meantime, Matthew decided to sign up for a consultation with a neurosurgeon to learn further about deep brain stimulation and see if this method is suitable for him. After all, he wants to stay active for as long as possible.



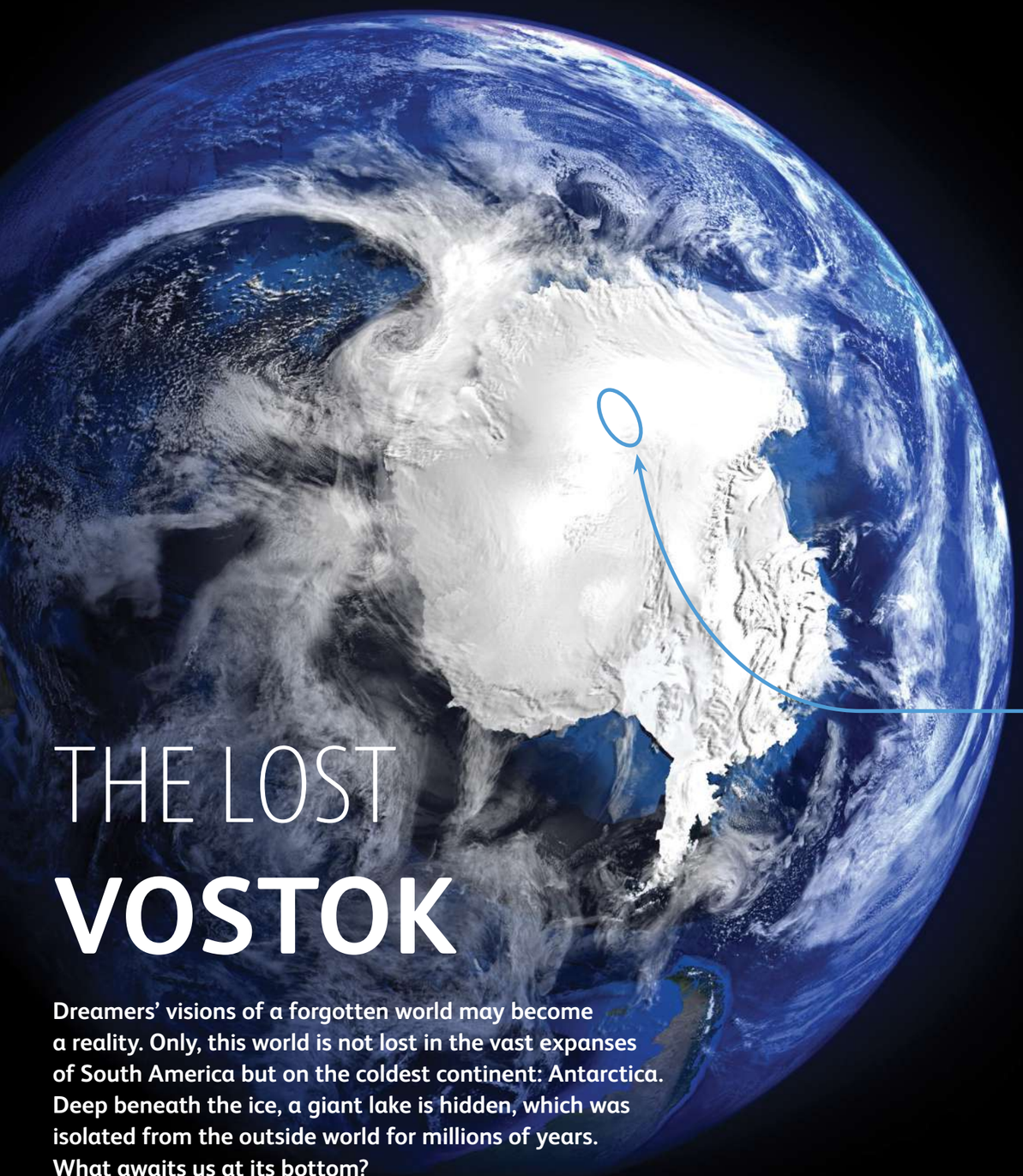
Shinya Yamanaka is a Japanese scientist and winner of the 2012 Nobel Prize in Physiology and Medicine

Dopamine Neurons Made of Stem Cells for Transplantation



The idea is to replace dead neurons. After transplantation, young neurons form connections with existing cells and produce dopamine. Scientists can reprogram mature cells — for example, skin cells, into immature stem cells, from which cells of other types can be developed. Stem cells are primitive, divide actively, and are able to develop into more specialized tissues (like neurons) through a process known as differentiation. At first, they are multiplied in laboratory conditions, and then, by acting on various growth factors, they are converted into young dopaminergic neurons. Then, they are implanted onto the brain to replace those that are deceased.

Thus, stem cell therapy may prove to be a promising strategy for the treatment of Parkinson's. The main task at hand is to make sure that the cells do not become tumorous, and that they function normally after transplantation.



THE LOST VOSTOK

Dreamers' visions of a forgotten world may become a reality. Only, this world is not lost in the vast expanses of South America but on the coldest continent: Antarctica. Deep beneath the ice, a giant lake is hidden, which was isolated from the outside world for millions of years. What awaits us at its bottom?

Secrets of the Peaceful Continent

Antarctica was lucky: in 1959 in Washington, the 12 countries that had scientific missions on the continent signed an agreement to ban establishing military bases, conducting military maneuvers, and testing any kind of weapons on its territory. Since then, humans have gone there exclusively in the name of science. The results of the work of one such mission suggested that at a depth of several miles under the ice cap of Antarctica, the temperature is close to the melting point of ice. This assumption was expressed in 1957 and was the first step to a grand discovery. Another mission involved seismic soundings of ice in the area of the Soviet-operated Vostok Station (the word *vostok* means "east" in Russian), which was conducted by a scientific expedition led by Soviet geographer **Andrey Kapitsa**, son of Nobel laureate **Pyotr Kapitsa**. As a result, a signal was recorded, reflecting off a surface under the ice. For about 30 years, it served as evidence of the presence of a layer of frozen rock under an ice shell many miles deep. However, the reflecting plane was so smooth that even Andrey Kapitsa suggested that there must be a huge subglacial lake with a length of more than 155 mi, a width of over 30 mi, and a depth of more than half a mile!

It wasn't until the 1990s that a technique was developed to confirm the existence of a body of water. The powerful radar and modern radio-locating method of geomagnetic deep sounding (GDS) enabled a British-Russian collective of scientists, led by **Gordon Robin**, to get results that even the most consummate of skeptics could not doubt: there is a giant lake under the layers of ice. Its contours appear on the icy surface of the continent. Jeff Ridley proved this in 1993 through the use of extremely precise satellite laser altimetry. It turns out that the Vostok Polar Station is in the center of an icy plain that is as flat as a table and can be considered a projection of the lake onto the surface.

Borehole 5G

The water in the lake has been completely isolated from the outside world for several million years. However, evolution continued there, and biological species appeared and went extinct. Life underwater "froze," which, of course, means it is of great interest to researchers.

In 1990, the first thermal drills dug into the ice of Antarctica in the area of the Vostok station. The goal was to get to the lake and take samples of its unique water. It should be noted that Soviet scientific expeditions had been drilling into the ice of the southern continent since the 1970s – four of their wells were classified as being deep. Therefore, when the thermal borehole at Lake Vostok was drilled, the well was called "5G", from the Russian *piataia glubokaia*, or "fifth deep well." This was achieved through thermal boring, when ice is melted by the movement of a heated drill head. This required a huge amount of electricity – ten times more than with traditional mechanical drilling. For this reason, and also because of the poor quality of the ice patch selected, the researchers switched out the thermal drill for the electromechanical KEMS–132. This shift happened at a depth of 9,000 ft.

The lake was named Vostok in honor of the Soviet scientific station established in this district in 1957

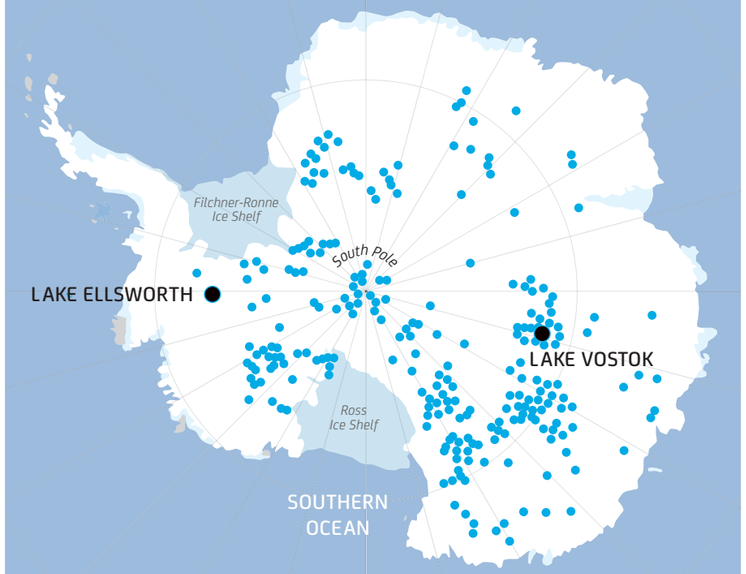
THE VOSTOK STATION

The climatic conditions at the Russian Vostok station are probably the most severe on the planet. In July 1983, the lowest temperature on Earth was recorded there: –128.6°F (in such cold, eyeballs freeze almost instantaneously). The altitude of the station, 11,443 ft above sea level, causes a constant shortage of oxygen among polar explorers. The multi-month adaptation required in these conditions is very taxing for the body: weight loss can reach 22–26 lbs for some living here. But people have been working at Vostok since 1957; they study the climate of the continent, its geology and, of course, drill into the ice of Antarctica for scientific purposes. In addition, the South Magnetic Pole, which is also an object of study, is located nearby. There is practically no life around Vostok, only trace amounts of microorganisms. During the summer, the station employs up to 50 people, while only 20 call it home during the winter months.

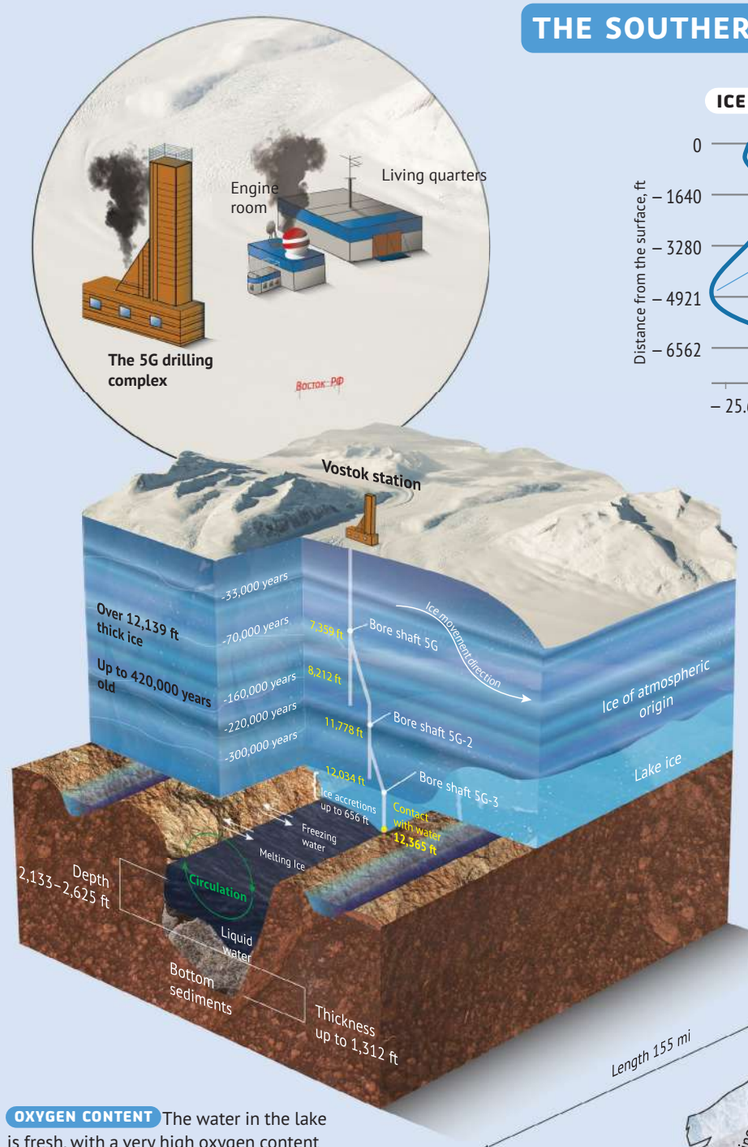
But in 1998, at the 11,886-ft mark, the work was stopped. Why? Drillers were using a mixture of aviation kerosene with a special weighting agent, freon, as drilling fluid. The weighting agent is necessary to fully compensate for the rock pressure of the ice mass: without it, the borehole may collapse into itself. Can you imagine what this poisonous mixture would do if it got into the lake? The majority of its unique biota would die as soon as the drill entered the water. That is why, for the purpose of preserving the lake's ecology, work was suspended for eight whole years, just a little under 500 ft away from the lake's surface. This was on the initiative of SCAR, the Scientific Committee on Antarctic Research. Later, oligodimethylsiloxane silicone fluid compounds came along to help researchers and drillers. This hydrophobic liquid, due to its chemical inertness, is harmless to humans and animals, which means there is a good probability that its effect on the microorganisms of the lake is also neutral. Additionally, the mechanical drill was replaced with a thermal one. ▶

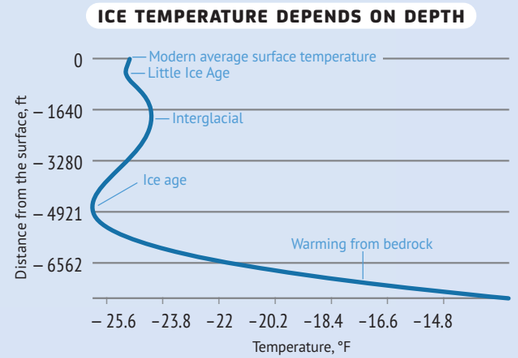
MAP OF THE SUBGLACIAL LAKES OF ANTARCTICA

Through the use of radar and satellites that penetrate through the icy depths, over 150 subglacial lakes have been discovered under the Antarctic ice sheet.



THE SOUTHERN OUTPOST OF SCIENCE





TEMPERATURE Vostok is located at one of the coldest places on the planet. On July 21, 1983, a temperature of –128.6° was recorded at the station, the record low of the 20th century.

AIR Antarctica is one of the driest places on Earth. Therefore, the air near the station has zero absolute humidity and is also strongly ionized. Polar explorers often experience respiratory problems due to low oxygen content.

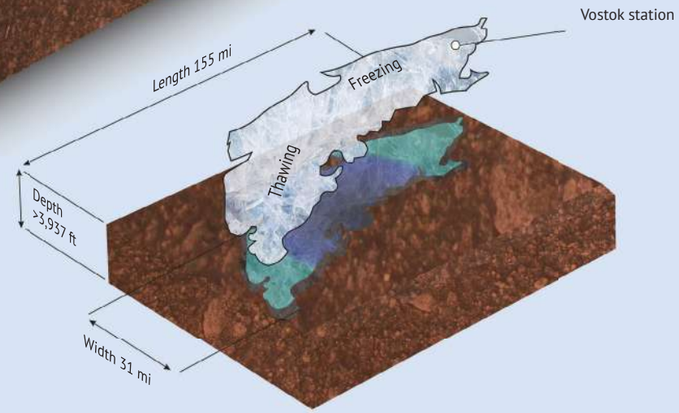
POLAR NIGHT Lasts for 120 days.

STAFF OF RESEARCHERS During the summer, there are about 50 people at the station, while during the winter months, it is staffed by only 20 scientists and engineers.

OXYGEN CONTENT The water in the lake is fresh, with a very high oxygen content (50 times higher than the norm). Oxygen enters the water from melting ice.

WATER TEMPERATURE At that depth, the temperature fluctuates around 50°. The water is presumably heated by underground geothermal sources.

PRESSURE Calculations show that the pressure in the lake is over 300 atm; these conditions are created by the thickness of the ice.

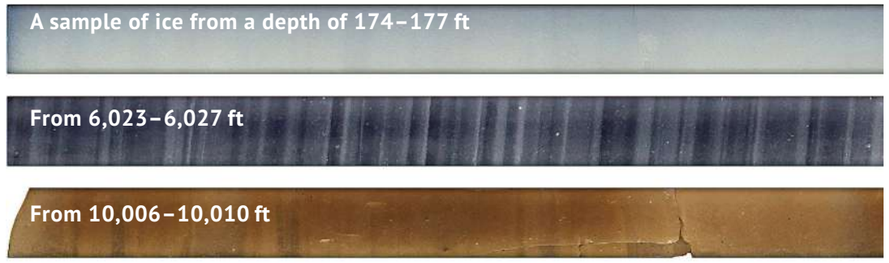


Cargo is delivered by plane in the summertime; in winter, it is almost impossible to reach the station

In 1989, a team of researchers from France, the USSR, and the USA began drilling the SG–1 borehole. The project aimed to study changes in the Earth's climate.

ICE CUTTINGS FROM DIFFERENT BOREHOLE DEPTHS

The ice shell on the surface is constantly forming as snow is compacted by new precipitation and becomes immersed in lower layers, where it has a granular structure and is located at a depth of up to 177 ft. Further on, it becomes denser — in the more recent snow, up to 6,027 ft, bands of annual snowfall are clearly visible. At the bottom of the borehole (10,009 ft), the ice has impurities of sand and silt. The lower the layer of ice, the more pressure it is under.



The TBPO-132 creates an additional buffer layer in thawing water under an organosilicon wash solution. The density of the liquid in the well had to be lowered so that its pressure was 0.3–0.4 MPa, below the estimated pressure in Vostok. This way, the drilling mud would not enter the lake. The water had to independently travel 100–130 ft upwards in the borehole and instantly freeze. It was proposed that the "fresh" relict ice be obtained with the help of a mounted electromechanical drill.

The Uncovering

On November 28, 2011, a new drilling unit arrived at the Vostok Station to undertake its journey downwards. By January 12, 2012, the ice-borer reached a depth of 12,262 ft, and on February 4, at a depth of 12,355 ft, it came into contact with the surface of the water, thus ending the under-ice lake's 15 million years of isolation.

Much of this complicated technical operation did not go as planned. In particular, it turned out that the water temperature in the lake was 27.23°, and that the pressure there exceeded 400 atm! Therefore, the water from Lake Vostok rose 2,000 ft through the borehole, mixing with the drilling fluid and freezing. About 8-10 gal of water mixed with water-polluting microorganisms was extracted from the surface. A year later, they managed to isolate a 6½-foot ice core and investigate its composition. However, ice in the hole complicated the re-drilling, so on January 15, 2015, scientists made a parallel well and re-entered the relict snow.

Predictably, no dissolved organic carbon was found in the ice, but it was highly saturated with oxygen — up to 0.11 oz per gallon, which is ten times higher than the limit values at which bacteria can survive. Microbiologists had to spend a lot of time isolating the so-called **contaminant** bacteria that got into the samples as a result of external contamination. But it wasn't long before they discovered rare species.

In 2016, the staff of the cryobiology laboratory at the Petersburg Nuclear Physics Institute announced the discovery of a microorganism, for now classified by the code w123–10. Around 14 % of this microbe's genome is composed of unique nucleotide sequences, which makes it possible to classify it as previously unknown. Interestingly, this organism was not the first underwater "alien" to be discovered: in 2004, even at a drilling stage of just over 1¾ mi, *Hydrogenophilus thermoluteolus* bacteria was found. These organisms are characterized by their unique ability to live at –58°. Don't let the relatively low number of organisms found so far mislead you: to this day, wherever water has been found on Earth, so, too, has life. There are still many discoveries ahead.

Lake Vostok cannot be called unique: in Antarctica, there are well over 400 under-ice reservoirs, though they are much smaller in size. For example, Lake Ellsworth, according to the hypothesis of British scientists, has been isolated from the outside world for more than 125,000 years and is now becoming an important object of research. Water samples from the small subglacial Lake Whillans (just a few feet below a 2,600-ft ice sheet) were collected by US polar explorers in early 2013. It turned out that the lake is inhabited by colonies of microorganisms, whose concentration is only ten times lower than in oceanic water. These bacteria do not get their energy from the Sun, but rather from breaking down carbohydrates.

Decades of research on unique lakes have allowed us to only barely touch the surface of underwater, icy relicts, and these attempts can hardly be called wildly successful. Scientists suggest that if life flourishing in Vostok is closer to the bottom of the lake, where temperatures are not as low, deep immersion into these subglacial waters could provide answers to many questions, including the possibility of life beyond our planet.

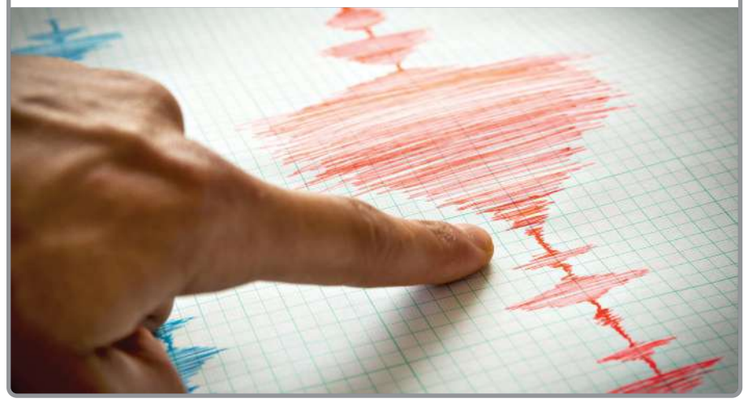
Take Saturn's moon, Enceladus, for example. It is covered with many miles of icy crust. Underneath, there could be a hidden ocean, full of life. And Enceladus is not unique: Jupiter's moons, Ganymede, Callisto, and Europa are also presumably home to deep oceans. Lake Vostok can become a model for the development of extraterrestrial life. We won't be able to land on the satellites of Saturn and Jupiter in the foreseeable future, but it is quite possible to penetrate the depths of a terrestrial subglacial lake.

This epic of the depths of Antarctica is a remarkable example of cooperation between the international scientific community, where relations between countries and individual people are not overshadowed by military operations or political sentiment. The Scientific Committee on Antarctic Research has become a roundtable where leading scientific powers share information and synthesize their knowledge on the challenging business of studying Antarctica. We continue to follow the quest of the "lost Vostok"— the future promises to surprise us!

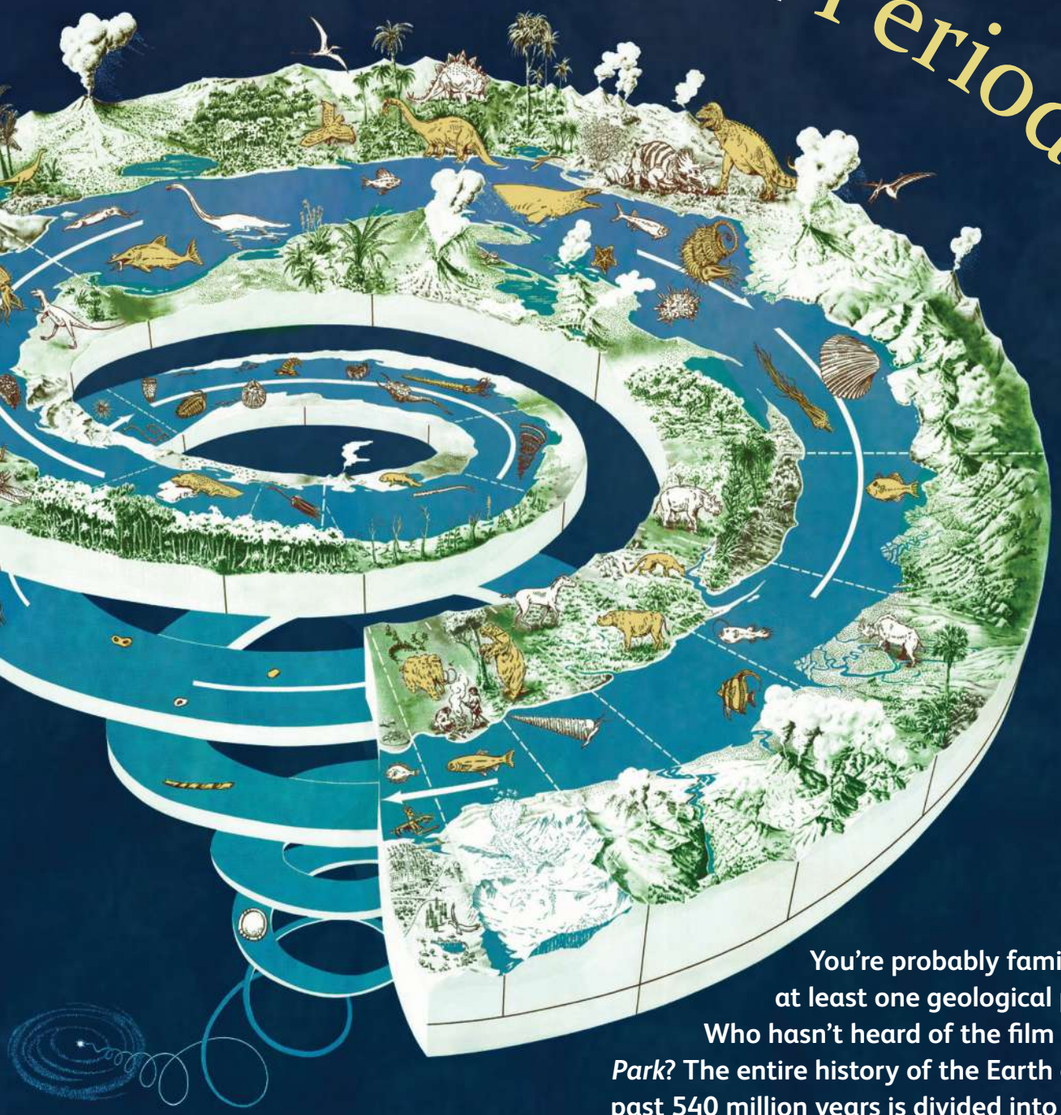
The extremely weak current in Lake Vostok implies that the floor sediments have stayed unchanged for millions of years. This is a very enticing opportunity for geologists, who could possibly determine the history of the whole continent based on this sediment alone. Its shape and composition can tell us about the climate and movement of Antarctica's ice sheet. For now, geologists will keep studying the borehole that has already revealed information about the climate over the last 400,000 years!

SOUNDING THE EARTH

While exploring the depths of the planet, scientists carry out **mini-earthquakes** of sorts. Typically, these are powerful explosions, the shockwaves of which are directed into the ground. Based on the behavior of the waves as they travel through rock, we can determine the structure of the crust of the Earth. Seismic survey stations are installed to record the reflected seismic waves, which help us to, among other things, find oil and gas deposits at extreme depths, as well as caves and subterranean lakes. Seismological studies of Antarctica in the late 1950s made it possible to make an important discovery, determining the thickness of the ice sheet, which turned out to range from 1½–2½ mi. This method makes it possible to conduct a fairly accurate reconnaissance, but it is very energy-consuming and expensive. A more modern method is geomagnetic deep sounding, in which a powerful radar "radiates" the Earth's crust with electromagnetic pulses, recording the signal reflected back. This method, which employs a ground-penetrating radar installed on an airplane, was used to determine the true dimensions of the subglacial Lake Vostok.



Geological Periods



You're probably familiar with at least one geological period. Who hasn't heard of the film *Jurassic Park*? The entire history of the Earth over the past 540 million years is divided into periods, which are in turn divided into epochs and centuries. But how do geologists know when a particular stage started and ended?

Stone Chronicle

How can we even begin to understand what was happening on our planet millions of years ago? Our main source of information is rock formations that developed during those distant eras. By studying them, geologists can try to reconstruct the conditions that existed at the time of their formation. For example, if a layer of solidified lava or volcanic ash is found, it is evident that a volcano was erupting nearby. A layer of clay suggests that there was a sea, and quite a deep one. In addition, fossilized remains of ancient animals and plants are often preserved in sedimentary rocks, which can be used to restore their appearance.

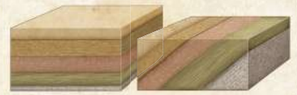
If we find a place where several different layers are visible one above the other (this is called a **geological outcrop**), then it is logical to assume that the higher up the layer, the later it was formed. This method was applied in the 17th century by the Danish scientist **Niels Steensen** (also known as Nicolaus Stenonius or Nicolas Steno) — today, this idea is called Steno's law of superposition. Based on it, you can determine the **relative age** of rocks that are in one place; that is, we can understand which rocks formed earlier and which formed later. However, this does not help us to determine how many millions (or maybe thousands? or billions?) of years ago they appeared: their **absolute age**.

Geological outcrops in Karijini National Park, Australia

Steno's Laws of Stratigraphy

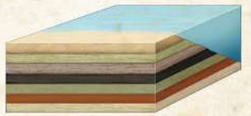
The Law of Superposition

Younger layers of rocks are located on top of older ones



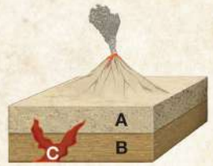
The Law of Original Horizontality

Layers of sedimentary rocks are initially flat, parallel to the horizon



The Law of Lateral Continuity

Rock layers are continuous until they collide with other solids that block their deposition, or until they are affected by agents that appeared after deposition occurred



The Law of Cross-Cutting Relationships

Rock layers A and B must be older than the intruder C

From Layers to Centuries

Can we compare the ages of rocks from different outcrops? It is clear that if the layers are located close to each other, at a distance of only several miles, then the rocks contained in them will most likely be very similar, if not identical, so it will not be difficult to compare them. But if the outcrops are located hundreds or thousands of miles from each other, or even on different continents, the rocks in them are likely to be different, and direct comparison will be impossible. A way to solve this problem was proposed in 1799 by the British engineer **William Smith**.

William Smith's geologic map of England and Wales >

Sketch of a sequence of layers and their relative heights v

< Index fossils by which William Smith identified one of the geological layers

Working on the construction of canals in different parts of England, he noticed that the findings in rock layers exposed by canal excavations did not occur randomly. Each rock layer is characterized by its own set of fossils — the mineralized remains of organisms and traces of their life activity.

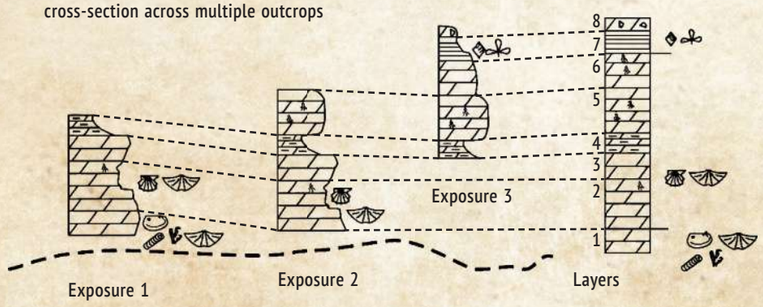
Moreover, the order of these sets of fossils is the same in different places. When Smith decided to classify rock layers based on these sets of fossils (which is why they are called index fossils), it turned out that the vertical sequence of the layers is the same everywhere. He then assumed that layers with the same index fossils were formed at the same time, and he combined layers from several different outcrops in one diagram.

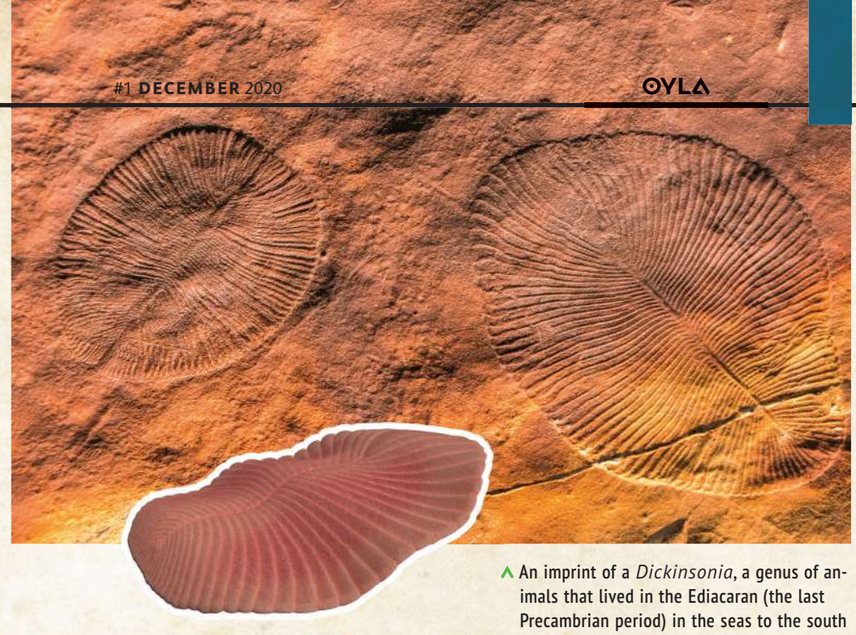
As a result, he obtained a framework for the sequence of layers with the same index fossils (geologists call them **strata**) — a geologic time scale. Each layer corresponds to the time interval in which it was formed. Based on this finding, Smith made a geologic map of England and Wales in 1815 (this was the first time in history that such a vast territory was mapped by geologists). The map looked very modern: it displayed the distribution of rocks on the surface, with rocks of the same age represented by the same color.

Over the next two and a half decades, geologists systematized the geologic time scale, identifying large geological layer systems and their corresponding time intervals, **periods**. By 1841, almost all the existing periods had been determined. Their names are derived mainly from the names of localities where the corresponding deposits are widespread. Thus, the name of the Devonian Period comes from the County of Devonshire in England; Permian from the city of Perm in Russia; and the Jurassic from the Jura Mountains on the border of Switzerland and France. In some cases, names of characteristic rocks were used.

For example, there are many coal beds in the Carboniferous deposits, and chalk deposits in the Cretaceous. By the end of the 19th century, the periods were grouped into three eras — the Paleozoic, Mesozoic, and Cenozoic, and divided into smaller parts: epochs and centuries.

v Diagram for building a geological cross-section across multiple outcrops





In Search of Absolute Time

However, it remained completely unknown how long ago all these periods took place and how long they lasted. There have been attempts to estimate the rate at which precipitation accumulates in modern seas and, based on this value, to calculate the length of periods during which layers of known depth have accumulated. However, this is a very slow process — usually, over the course of 100 years, not even half an inch is deposited; and in addition, over time, precipitation is strongly compacted (though it was not yet known by how much). So, this method did not provide us with any reliable data. Therefore, scientists relied mainly on estimates of the total age of the Earth and then tried to calculate the length of each period, assuming that its share in the total history of the Earth is proportional to the share of the corresponding deposits in the combined section. The problem was that it was also impossible to determine the age of the Earth very accurately. For example, in 1868, the British physicist **William Thomson** (who later received the title of 1st Baron Kelvin for his scientific achievements), based on a mathematical model, suggested that its age is 20-40 million years — during this time, the once-hot planet would have cooled to its present temperature.

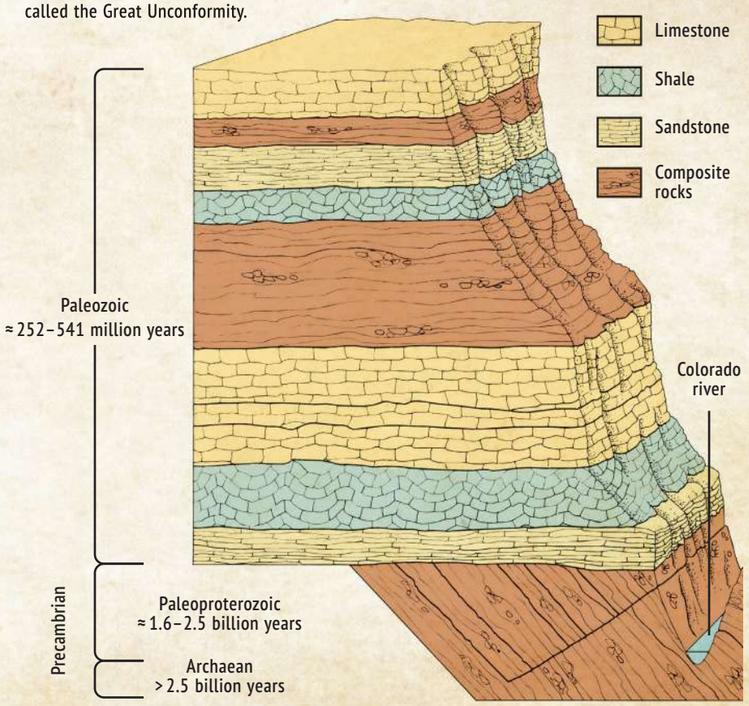
^ An imprint of a *Dickinsonia*, a genus of animals that lived in the Ediacaran (the last Precambrian period) in the seas to the south of modern Australia

v Sometimes entire "pages" of Earth's history are lost due to rock erosion or other factors. For example, the neighboring layers of sedimentary rocks of the Grand Canyon vary greatly in age. The lower formations belong to the Precambrian, while the upper ones belong to the Paleozoic era. Almost a billion years have been "lost!" This phenomenon is called the Great Unconformity.

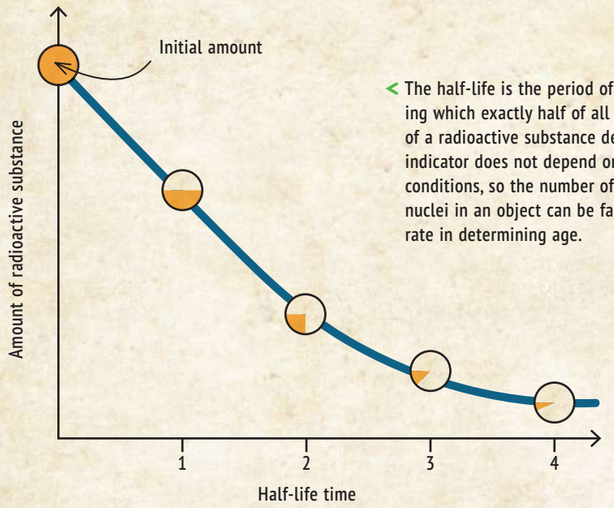
This model did not take into account many parameters, so it is not surprising that the result was incorrect — more than a hundred times younger than the current estimate! But until the end of the 19th century, this value was accepted by most scientists. It is clear that the length of geological periods based on this figure were also greatly underestimated.

The Problem of the Precambrian

In the 19th century, the geologic time scale was designed only for rocks that were formed no earlier than the Cambrian period. In the previously-formed rocks, it was absolutely impossible to find not only characteristic sets of fossils but any traces of life at all, which means that the principle of combining layers according to the index fossils, as developed by Smith, did not work. In the 20th century, traces of life in Precambrian deposits were found, but the Precambrian periods are still mainly distinguished not by characteristic sets of fossils but by the results of absolute dating.



Law of Radioactive Decay



< The half-life is the period of time during which exactly half of all the nuclei of a radioactive substance decay. This indicator does not depend on external conditions, so the number of decayed nuclei in an object can be fairly accurate in determining age.

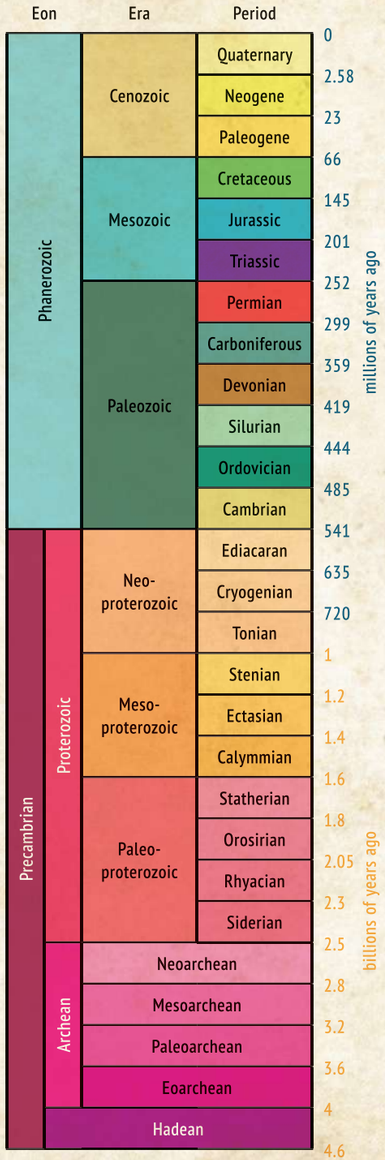
The situation changed when the French chemist **Henri Becquerel** discovered the phenomenon of radioactivity in 1896. In 1904, the British physicist **Ernest Rutherford** discovered that radioactive isotopes have a certain period of time, independent of external conditions, during which half of their initial amount decays, and he called it the half-life. At the same time, he proposed the idea of **radiometric dating**. This technique is based on the fact that if a mineral contains a radioactive isotope, by determining the ratio of the mass of this isotope to the mass of the isotope formed as a result of decay, you can calculate the time of formation of the mineral.

The first experiments in radioisotope dating, conducted independently in 1907 by Rutherford and the American radiochemist **Bertram Boltwood**, although very inaccurate, still proved that there are minerals on Earth that are at least two billion years old, and therefore the planet itself can be no younger. In the following years, dating technologies further developed, and in 1956, the age of the Earth was determined to be approximately 4.54 billion years — since then, this estimate has not changed much.

It would seem that radiometric dating would allow you to determine the age of not only the Earth but also any rocks that contain radioactive isotopes. However, the age of a rock rarely coincides with the age of its constituent minerals. For example, a layer of sand may have been deposited ten thousand years ago, while the grains of quartz that make it up were formed millions or even billions of years ago. Therefore, only those rocks that were formed simultaneously or almost simultaneously with the minerals that make up their composition are suitable for radiometric dating — that is, igneous rocks that arose as a result of the cooling and solidification of magma or lava.

At the same time, the geologic time scale is based, as you already know, on the order of sedimentary rocks. Therefore, geologists usually follow this procedure: find a layer of igneous rock lying between two successive strata of sedimentary rocks and date it, thus determining the absolute age of the boundary between these strata. By now, all borders have been dated using this method, not only between periods but also between the epochs and centuries that make them up. But due to the fact that dating is constantly being refined, geologists still prefer to use relative rather than absolute age.

Geologic Time Scale



^ The Phanerozoic Eon (which began 541 million years ago and continues to this day) is the largest interval of geologic time. It is famous for its abundance of living organisms, the components of fossils in sedimentary rocks.

Exact Boundary

The boundaries between successive strata look slightly different in different outcrops: after all, strata may be composed of different rocks, and the set of fossils varies slightly from place to place. Therefore, geologists agreed to find a section for each boundary between strata in which it would be most noticeable, called the stratotype. When you highlight the boundaries between strata in other outcrops, the stratotype is used as a reference.

Dating	Relative	Absolute
Methods	Steno's Laws, paleomagnetism, paleopalynology (the study of fossilized pollen), nitrogen dating, etc.	Radiometric, uranium-lead, optical, thermoluminescent, archaeomagnetic dating, dendrochronology, etc.
Description	Relative dating methods cannot determine the absolute age of an object or event, but they can determine whether event A occurred before or after event B.	Absolute dating methods using absolute referent criteria mainly include radiometric dating methods.

Our Epoch

The Quaternary Period began 2.6 million years ago, and it continues to this day. Until recently, geologists divided it into two epochs — the Pleistocene, which covers almost the entire period, and the Holocene, which began only 11,700 years ago. However, in 2016, delegates of the 35th International Geological Congress, held in Cape Town, voted to allocate a new epoch — the Anthropocene.

Their main arguments focused on the sharply-increased impact of human activity on Earth, which is expressed in the mass extinction of species, global climate warming, and environmental pollution, including substances not found on Earth in nature (plastic, aluminum, reinforced concrete). As a marker of the transition to a new era, it was proposed to designate the sharp increase in radioactive isotopes in sediments around the world, associated with the beginning of nuclear testing. Thus, for the beginning of the Anthropocene, you can specify the exact date of reference: July 16, 1945, when the first nuclear bomb was detonated at the Alamogordo test site in New Mexico.

v Crushed stone and asphalt are typical deposits of the Anthropocene

A Vegetable Garden without Soil

Science and technology don't stand in place: scientists around the world work to ensure that the production of fresh and healthy foods is simple, cost-effective, and environmentally friendly. So, in place of classic garden beds and greenhouses comes hydroponics: growing plants in nutrient solutions without soil.

The History of Hydroponics

The idea of growing plants without soil is not new. Back in 1699, the English naturalist **John Woodward** described his experiments growing peppermint in a soilless environment. The plant died in desalinated, distilled water, but it continued to grow in untreated water. Probably, Woodward reasoned, the mint extracts something from the water that is necessary for growth.

Now we know that the plant needs many mineral substances for normal growth and development, including *calcium* (***Ca***), *iron* (***Fe***), *potassium* (***K***), *magnesium* (***Mg***), *phosphorus* (***P***), and *sulfur* (***S***). Plants take them from the soil (some predators, like Venus flytraps, get them from the bodies of their victims), but for this, there must be water in the soil to dissolve the mineral substances, making them accessible to the roots. Plants don't need the soil itself, they just require mineral substances from it. Woodward's experiments gave rise to much reflection, but, until the beginning of the 20th century, the cultivation of plants without soil remained an area of exclusively scientific interest.

In the 1930s, American biologist **William F. Gericke** brought hydroponics out of the laboratory and into the light. He insisted that growing plants on a large scale without soil, but instead on nutrient solutions, is not only possible but also makes a lot of sense. His colleagues were skeptical about this idea at first, but when Gericke showed them tomato shrubs a few yards tall that were grown with an aqueous solution of mineral substances, they changed their mind. The University of California, where Gericke worked, even allocated huge areas for such experimental greenhouses. He called his revolutionary method "aquaculture," but there was some confusion: the word was already in use for the breeding of aquatic organisms (fish, algae, mollusks). It was then that he introduced a new term—**hydroponics**—which we still use to this day, as it carries the understanding that this is the cultivation of plants using nutrient solutions and without soil.

NASA is studying the prospects of growing vegetables in space

The first mention of the commercial use of hydroponics was in 1938 when *Time* magazine published an article about tiny Wake Island in the Pacific Ocean, where Pan American Airways planes landed for refueling. Among other things, the article said that barrels with mineralized water, in which beans, tomatoes, and other vegetables were grown, were installed on the island. This food was intended for the aircraft crew. During World War II, there were more of these kinds of farms: the military needed fresh vegetables, and it was difficult to deliver them. Today, hydroponics is widely used all over the world. For example, NASA is studying the possibility of growing vegetables on a spaceship in a closed ecological life-support system. The success of such an experiment will lead to new prospects for space travel.

Why Water Is Better Than Soil

Humankind has been growing fruit and vegetables for thousands of years. Why spend money on technological development when you can just stick a plant in the ground? Because hydroponics has a lot of advantages. It gives us the opportunity to grow food in places where traditional agriculture is impossible. In arid climates, like Israel and Egypt, hydroponics has been used for several decades. Thanks to this method, it became possible to purchase locally-produced food on the market, rather than importing these products from other countries at a high cost. Similarly, hydroponics are needed where space is limited, even for humans. For example, in Bermuda, these systems occupy only 20 % of the amount of land that would be required for crops. In regions that are cold and have few sunny days, hydroponics allows you to harvest a high yield of local vegetables and fruits. In cities with poor ecology, the cultivation of plants without soil solves several problems at once: greenery appears, which is typically rare in densely built-up areas, and along with it, food products start to grow in homes and offices, which leads to almost unlimited access to fresh, healthy food. The deciding argument in favor of hydroponics is the high environmental friendliness of this type of agriculture. The water circulates in a closed system: it passes through purification systems, is enriched with nutrients, and again flows to the plants. This is extremely important for areas where there is little water, such as in the Middle East and parts of Africa. Besides, almost no pesticides are required: the conditions on farms are practically sterile, and hydroponics require only about 25 % of the amount of fertilizer necessary for growing plants in soil. This approach saves money and contributes to the preservation of the environment. Finally, since the food is grown on-site, there is no need for it to be transported — again, both the producer and nature benefit.

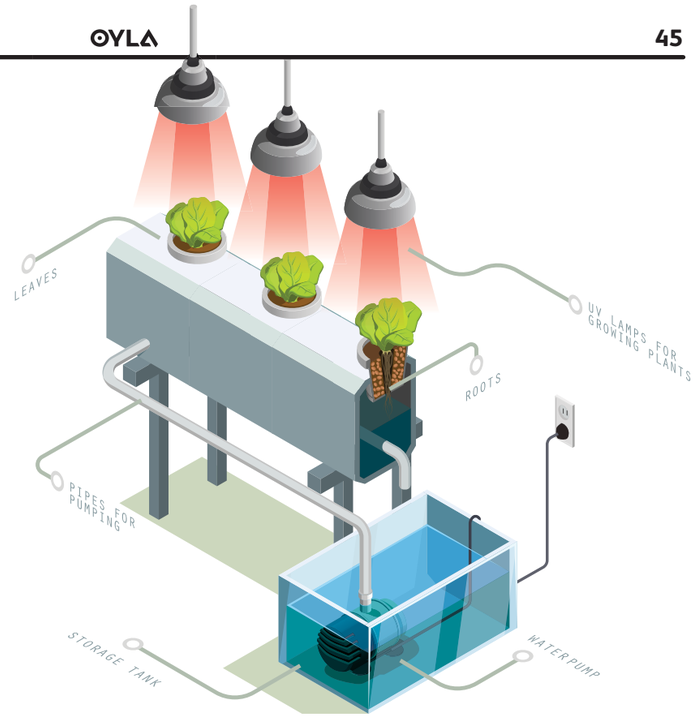
The idea of hydroponics is that soil is not an obligatory companion of plants, but is rather just support for it. Therefore, the substrate can have many different compositions — coconut fiber, sawdust, mineral wool, crushed stone, expanded clay, etc. It is only important that it conducts moisture well, allows air to circulate, and does not chemically react with the nutrient solution. By the way, moist air can also serve as a substrate (this is called aeroponics).

Hydroponic garden

The Structure of Hydroponic Farms

Hydroponic farms are similar to conventional greenhouses, but instead of beds, there are special shelves, under which grooves with nutrient fluid are located. Seeds are kept in a special incubator until the first shoots appear, and only then are they sent to the hydroponic farm. Since the roots of plants are immersed directly in the nutrient solution, vital substances do not need to break through the soil layers, the root system grows minimally.

Thus, all organic substances synthesized by the plant go to the construction of shoots, leaves, and fruits. Under such conditions, the plant grows extremely quickly: a salad bush on the soil bed grows in a couple of months, while in a hydroponic farm, it takes only 30 days. To obtain a large crop, it is not enough to just provide plants with nutrients. The growth of crops is affected by many factors that need to be kept under control. To do so, dozens of sensors are installed in the greenhouses: they monitor the acidity and electrical conductivity of water for irrigation, ambient temperature, humidity, brightness, and CO_2 supply.



How Does a Hydroponic System Work?

Well-designed heating systems located near the plants create a uniform temperature regime around the plant and enhance gas exchange. Artificial lighting allows you to control the development of plants, to accelerate or slow down flowering, and to affect the maturation process. All you have to do is extend daylight and the development of long-day plants will accelerate, which means that the harvest can be collected much earlier. Knowing exactly how each part of the light spectrum operates on cultivated plants, scientists and engineers have created phytolamps that emit light in the red and blue regions of the spectrum. Conditions are created to enable the maximum intensity of photosynthesis, and plants begin to grow faster. The conditions in the greenhouses are so conducive to growth that the plants grown in them are always beautiful, bright, and juicy, just like in the pictures.

Ripe strawberries grown in hydroponic farms are an object of agricultural tourism in Israel. Tourists can take part in harvesting at any time of the year.

Vertical Farms

In the near future, the growth of the world's population will lead to a shortage of arable land.

Vertical farms allow us not only to abandon soil but also to use space economically, placing hydroponic installations in several tiers.

WHY HYDROPONICS?

Does not require soil

A reusable substrate is used

Simple technology

Does not require special skills or knowledge

Year-round harvests

Fast growth in any season

Control

The composition of the nutrient solution can be changed

Eco-friendly

Small quantity of fertilizers and pesticides

Water-efficient

Through water reuse

How Do You Plant a Hydroponic Garden at Home?

MATERIALS

- A young, healthy plant (it will adapt more easily to a new habitat)
- A planter (must be opaque; otherwise algae will start to grow and not let water pass through)
- An inner plastic pot with drain holes (to allow air and nutrient solution in); it should be able to sit "suspended" in the outside pot
- A substrate of expanded clay (you can buy this in a flower shop)
- A hydroponics nutrient solution (you can buy this in a flower shop as well)
- Clean, room-temperature water
- Water level indicator

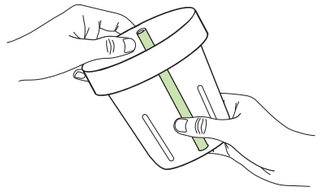
METHOD

1

The day before the transplant, water the plant well. Thoroughly rinse the roots with warm water, so that they do not have any soil left on them. Remove rotten and damaged roots.

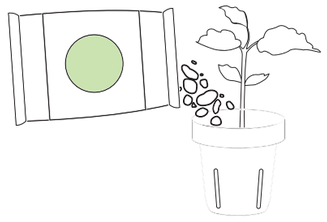
2

Insert the indicator into the inner pot.



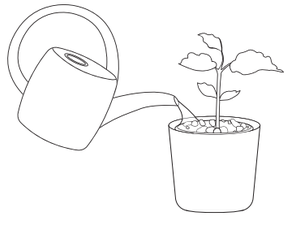
3

Spread the roots of the plant and surround them with expanded clay.



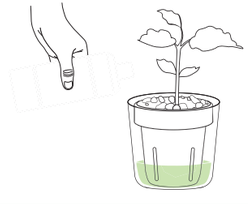
4

Place the inner pot inside the external one and pour clean, room-temperature water into the outer pot. If you immediately pour a nutrient solution, the plant will be under stress and may die.



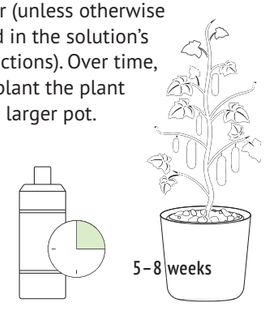
5

Put the pot in a warm and bright, but not very sunny place. In a week, the plant can be watered with a solution for hydroponics until the liquid fills one-third of the inner pot. When adding the nutrient solution, watch the water level on the indicator.



6

Change the solution once a month in the summer and once every 5–8 weeks in winter (unless otherwise stated in the solution's instructions). Over time, transplant the plant into a larger pot.



THE PETRI DISH AND ITS STORY

From the first antibiotics to the growth of stem cells, from observing microorganisms to the testing of new medicines — it's all possible thanks to the Petri dish, a short, flat cylinder covered with a transparent lid of a corresponding shape. This humble glass plate has its own fascinating story.

A Pure Culture

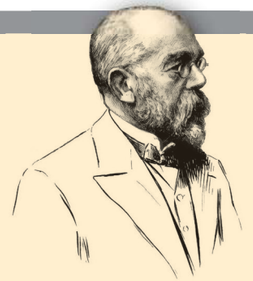
In 1872, **Robert Koch**, who would later become a renowned microbiologist, was named the District Medical Officer in Wollstein (now Wolsztyn in Poland), where an anthrax outbreak was running rampant at the time. The disease was known even back in antiquity when it was called "sacred fire": people thought that only furious gods could have sent such a scourge to Earth. Anthrax was a threat to all agricultural settlements — more often than not, livestock were infected. However, animals were not the only ones to die: the illness also claimed the lives of farmers, shepherds, and milkmaids.

Looking through a microscope at the blood of the deceased animals, Koch discovered that the development of the disease could be blamed on a single *Bacillus* microbe (*Bacillus anthracis*). The researcher successfully isolated the bacteria and was able to grow a **pure culture** from it — a culture that is composed of a single type of microbe. He infected an entirely healthy animal with this pure culture, thus giving it anthrax. The scientist understood that the creation of a pure culture was the key to successfully determining the cause of an infection.

Koch, like his predecessors, developed bacterial cultures in a liquid medium, broths made of meat or cereal grains. Koch did manage to create a pure culture of *Bacillus anthracis* in a liquid broth, but he was still searching for another method, and with good reason. If several species of bacteria happened to get into the broth, they would mix together, making it extremely difficult to separate them. It was necessary to develop the bacteria more than once. Koch would take a small drop from the solution where the target bacteria were in the highest concentration, and then he would transfer it to a fresh broth. In this new broth, there were already fewer foreign bacteria, but he had to repeat this monotonous operation several times to achieve a monoculture of a single species of microbe in the growth medium.

WHY DO WE NEED PURE CULTURES?

Microbes are very small (0.5–5 μm on average) and do not differ much in appearance, which causes difficulties in studying them. For research, it is necessary to single out one microbe from the surrounding world, which is filled to the brim with radically different microorganisms. Microbial cells, after landing in the growth medium, produce offspring — a cluster of identical cells called a colony, which can be studied like a single microorganism. It turns out that, by manipulating the conditions of cultivation, it is possible to obtain a pure form of the cells of any microorganism. Thereafter, you give it a name, describe its properties, and classify it. Thanks to Koch's discovery, microbiology has been recognized as a science in its own right.



Robert Koch (1843–1910) was a German microbiologist. He discovered *Bacillus anthracis*, *Vibrio cholerae*, and *Mycobacterium tuberculosis* (Koch's Bacillus). In 1905, he was awarded the Nobel Prize in Physiology and Medicine "for his investigations and discoveries in relation to tuberculosis."

^ Before Robert Koch, researchers believed that microorganisms were colorless, which led to numerous mistakes. Koch used aniline dyes, which selectively stained microbes. After Koch's experiments, researchers around the world began to use this technique of dyeing bacteria. Then, in 1884, **Dr. Hans Christian Gram** developed a method of staining that became the primary approach to determining the presence of a type of bacteria in a given substrate.

< A macro image of *Mycobacterium tuberculosis* colonies. They are distinguished by a colorless, uneven surface.

Microorganisms divide approximately every 20 minutes, and therefore, only three hours after transplanting a microbe into a Petri dish, you may already see colonies. Within 24 hours, the number of bacteria is estimated to already be in the millions. >

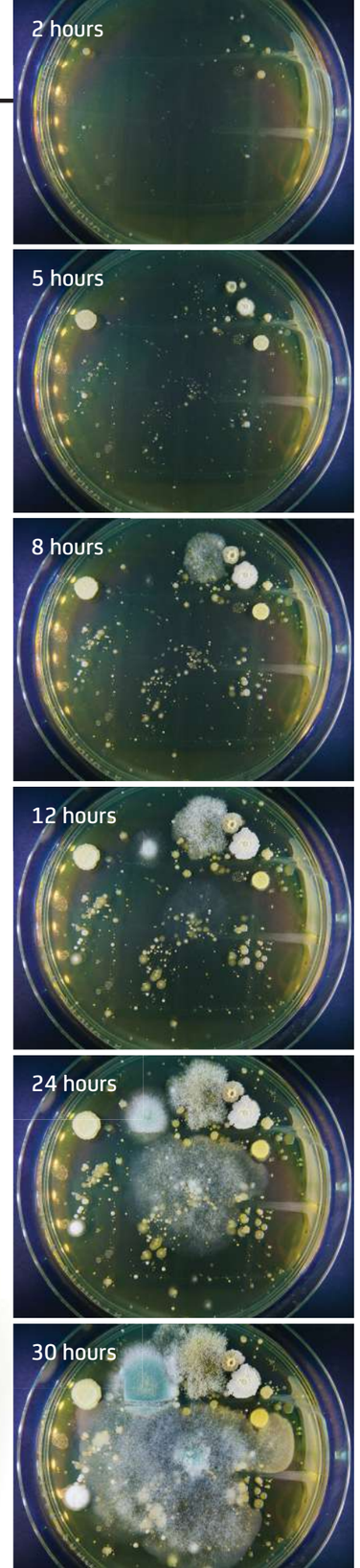
A Tough World

After his report on the discovery of the agent that causes anthrax, Robert Koch was invited to head a laboratory at the Hygiene Institute in Berlin, and he was offered the post of Advisor to the Imperial Health Office. Koch suddenly had good equipment, talented assistants, and the ability to solve a mystery that had long haunted him. It was known that tuberculosis was also caused by some kind of microbe: the tissues of a sick person could infect healthy animals. Koch managed to find a technique for staining prepared tissues to discern the pathogen bacteria under a microscope. But his joy didn't last for long — the bacteria did not want to grow in normal growth media.

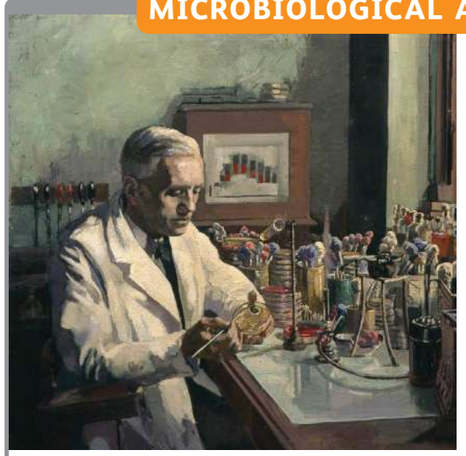
One day, the scientist noticed that a pile of moldy potatoes left on the table had an abundance of colored spots—colonies—of gray, yellow, and green. He collected samples from each colony, and he noticed under the microscope that each spot was a colony of a single species of microbe! In liquid media, the microbes mixed and separated, making them extremely difficult to work with. But in a solid medium, they stayed in a single spot, multiplying and giving birth to a pure culture!

Koch once again began to diligently cultivate tuberculosis cultures. Yet, the bacteria did not grow on the potato slices. He then began to use gelatin to turn the broth into a **solid growth medium**. After many unsuccessful attempts, Koch added blood serum to the substance to recreate the conditions of a living organism. After 15 days (it had never taken that long for *Bacillus anthracis*), droplets of colonies of the dangerous *Mycobacterium tuberculosis* began to appear on the surface of the medium.

Koch's accidental observation fomented a revolution: fresh potatoes became one of the first solid media for cultivating microorganisms. However, such a nutritious substrate was not suitable for all microbes, and, therefore, the search for an alternative solid medium continued. >



MICROBIOLOGICAL ART



< In 1928, the British bacteriologist Alexander Fleming discovered that in the agar in one of his Petri dishes, a colony of mold fungi had grown next to bacteria. Bacterial colonies around the mold turned pale: their cells had been destroyed. Fleming isolated the substance destroying the bacterial cells — penicillin, the first antibiotic created from mold. Fleming's discovery changed not only medical science but also the fate of many would-be hopeless patients.

British bacteriologist **Alexander Fleming**, who discovered penicillin, also created a new art form: drawing with bacteria on a solid growth medium. Fleming, as a member of the Chelsea Art Club, created "amateur" watercolors. The scientist painted graceful ballerinas, luxurious homes, soldiers, and other scenes using bacteria. The creation of a painting required patience: one needed not only to find bacteria of various pigments but also to calculate the time of cultivation so that a monochromatic area would grow simultaneously and not blur the lines between colors.

The American Society for Microbiology (ASM), inspired by Fleming and his colleagues, has held an "Agar Art Contest" every year since 2015. Talented microbiologists paint real pictures, some choosing their own subjects, while others reproduce famous paintings with astounding accuracy, such as Van Gogh's *Starry Night*.

A Talented Lab Assistant

At that time, the only piece of laboratory glassware that was suitable for growing microbes was a test tube. But handling it required skill: if you laid the tube horizontally, the unshielded medium would pour out; if you put it at an angle, it could fall and break. Your chances of catching a dangerous disease literally multiplied before your eyes! Then, Koch and his laboratory assistants came up with the idea of housing growth media in cups covered with high glass caps. But to observe the colony, you had to remove the cap, which was a surefire way to catch the infection. That's when one of the laboratory assistants, **Julius Petri**, had his moment in the sun. He reduced the height of the walls of the cup in which the microbes were developed and covered it with another transparent cup. This made it far easier to observe the colonies.

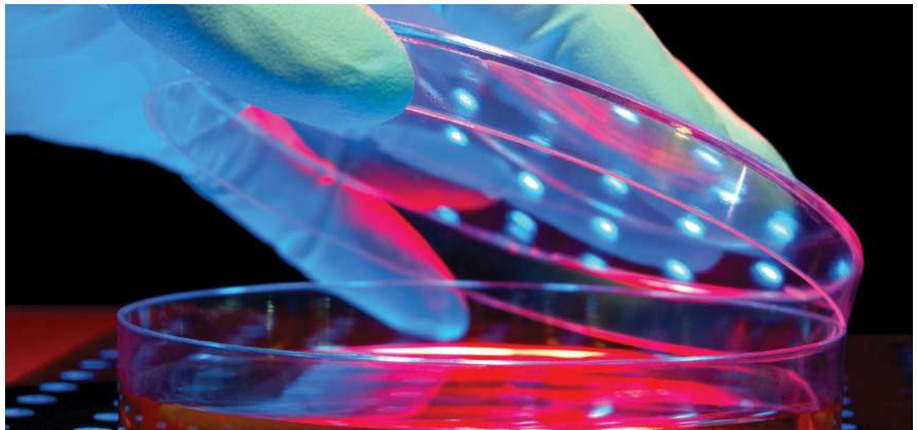
Petri worked under Koch's leadership for only a couple of years (1877–1879), but in that time, he radically influenced the future of microbiology. Petri's innovation gave medicine a powerful push and saved millions of lives. After his work with Koch, he went on to head the Gobersdorf Sanatorium, the first European center for treating tuberculosis patients.

Agar-Agar

Koch's laboratory did not just produce the Petri dish but also the standard filling for it, the agar growth medium. Its predecessor, the gelatin medium, melted easily when heated or kept in a warm place. In that environment, the colonies literally turned into a hot mess.

Walther Hesse, another laboratory assistant of Koch's, invented the medium that became the basis for agar. He joined the ranks along with his wife, **Fanny Hesse**, who was not a laboratory employee but worked as a scientific illustrator, sketching the organisms that she saw under the microscope.

One day, Fanny was making some jelly at home, and Walther noticed that it did not lose its shape or melt in the sun. He found out that the main component of jelly is agar-agar, a substance extracted from red and brown algae. Walther replaced the solid gelatin with this substance, and the bacterial growth media became firmer. Agar is used today for medium preparation, but it is purified with a special technique.



To determine the effectiveness of antibiotics in the pharmaceutical industry, special tests are used — for example, agar diffusion. In this method, microorganisms are set into Petri dishes and then antibiotics in various doses are placed on the surface at an equal distance from one another. The larger the radius of the inhibited growth zone, the more effective that medicine will be against the microorganism.

At first, the Petri dish was only used for growing cell cultures, but now it is widespread across many fields of science. For example, Petri dishes are used to study the effectiveness of antibiotics, the safety of different foods, and to develop genetically-engineered bacteria that synthesize insulin, a substance necessary for individuals with diabetes.

Petri dishes are made in different sizes and from a wide variety of materials: glass, plastic, and even stainless steel. All a scientist has to do is pick the one appropriate for their work.