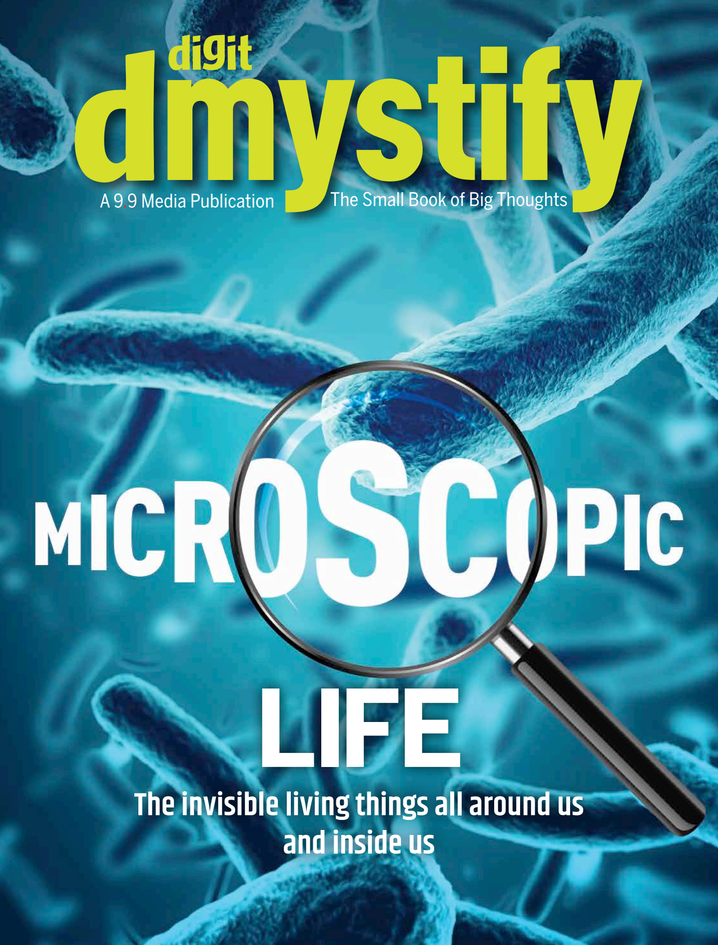

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The Small Book of Big Thoughts

MICROSCOPIC LIFE

The invisible living things all around us and inside us

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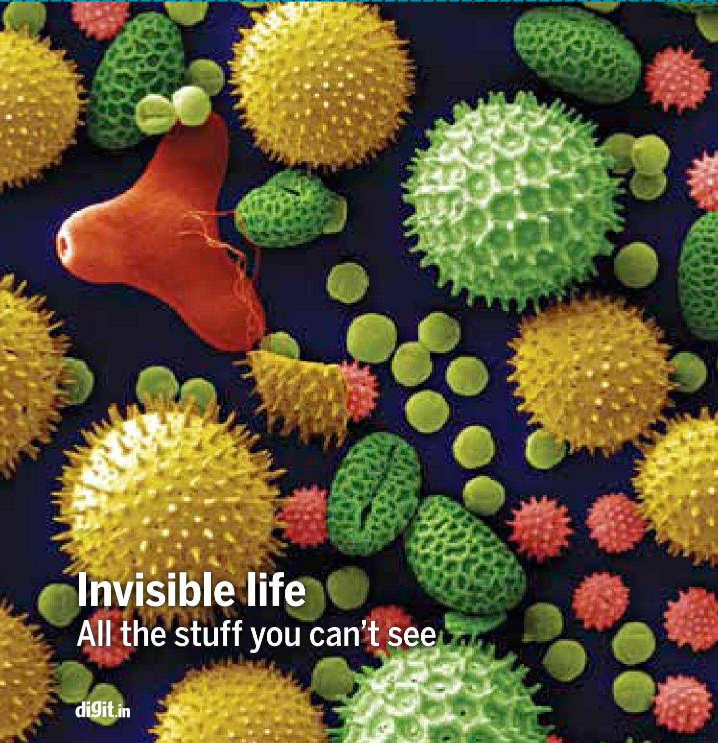
March 2017



Invisible life

All the stuff you can't see

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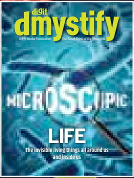
INSIDE



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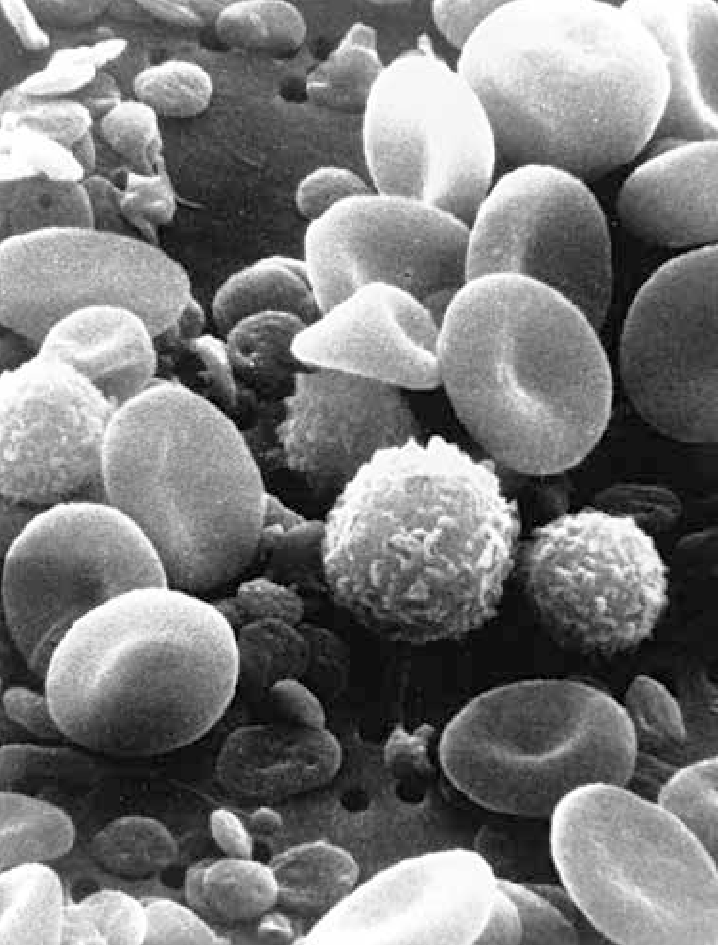


All the small things

We are not built to see or experience anything small. We're not built to see or experience anything very large either, and the idea of the true sizes of stars boggles our mind. However, just because we cannot experience it doesn't mean it doesn't exist.

When it comes to the microscopic world, there is so much that we don't see. We cannot see. Or rather, to be more precise, we couldn't see until we started using tools to enhance our senses to be able to start peering into the world of the very tiny. A mere drop of water was found to be a vast world of millions of tiny living (and nonliving) things. For example, it's estimated that one drop of seawater contains 10 million viruses, which we really cannot classify as "living" things, but which certainly interact with living things and invade and kill them like conquerors!

All over our skin, in the air, in the "clean" water we drink, inside our bodies, we're surrounded and filled with tiny organisms, and most have lived on this planet for just a shade under the time the planet itself has existed.

This book will take you into that world, to give you a very brief but mind-blowing glimpse of a world that you cannot see – at least not with your own eyes.

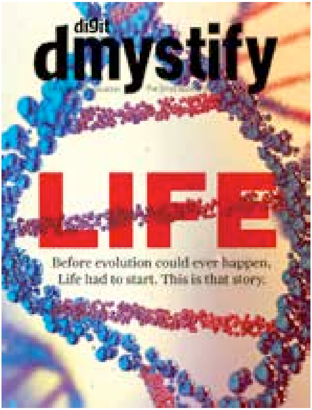
The image on the opposite page is an electron microscope image of our blood. ■

History

A look at how we humans discovered the very small

Let's start at the start, shall we? Our latest estimates of when life started on Earth is between 4 billion and 3.8 billion years ago, which is a mere 300 to 500 million years after the planet itself formed! We don't yet know how it started – we have pretty decent guesses – but we do know that life was microscopic. It started small, and then eventually grew. It took ages though, because for 3 billion years the earth was only inhabited by microscopic single-celled (unicellular) life.

Eventually, about 900 million years ago, multicellular life started off. Again, we don't really know how, because this is obviously close to a billion years ago, but we have our guesses. More about that later. Whatever happened, it caused life to explode and take off about 800 million years ago. It all ended quickly though, because about 770 million years ago the planet froze (snowball Earth).



Remember to check out our previous dmystify books!

It was only 535 million years ago that the Cambrian explosion occurred. Some suggest that the lack of older fossils might make this look like an explosion, whereas it might well have been a lot less explosive, and more gradual a progression of life. We might never know.

If you're interested in knowing about the details of how we think life evolved, you should read our dmystify Life book. What we do know for sure is that all of this eventually led to us humans, sitting here, reading about life.

For a long time in our human history we didn't know about microscopic life. We could feel the effects them, but we didn't really find a way to observe the really small, even indirectly.

This led to some interesting theories across antiquity about why certain things happened, and we're going to look at a few of them.

POISONOUS AIR!

Since antiquity adults, kids, pets, plants... humans have seen everything alive suddenly die. There's the death that comes from natural causes such as aging, but there's also been death that's sudden, or at least the onset of a sickness or illness is sudden, and that results in death.

While entire religions and Gods have been created to explain this, or to ward it off, there was also always some basic science that was done. For example, perhaps it was first noted that healthier people had a better chance of surviving sickness. Trial and error would lead to some herbs being found to be beneficial for some illnesses, or infections. However, it would all be guesswork about why such illnesses happened in the first place. Every civilisation would have had their own theories and explanations, and we're quickly going to run through a few here.

Indians: Being Indian, we're partial to ancient Indians, and India is after all one of only a handful of countries where medicine that was practised as early as 1,000 BCE is still practised today. Ayurveda medicine, for better or worse, is still very much in practice all over India, even today. India was also probably the originator of the idea of miasma. Although miasma is a Greek word meaning "bad air", ancient Indians are thought to be the originator of this idea.

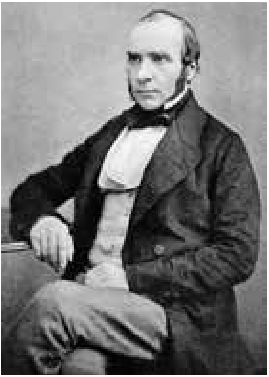
A typical ayurveda pharmacy

The idea of miasma is that rotting flesh or garbage and other waste products give off an odour, and this is because particles of the decomposed matter fill the air and cause illness. This pollution or bad air is what was believed to spread disease. It was not thought of as humans passing diseases on to other humans, it was considered that anyone who was exposed to this bad air would fall sick.

Greeks: As usual, the Greeks were amongst the first (in written history) to suggest that disease could be transferred from one to another. The Greek historian Thucydides (460 to 400 BC) is known to have expressed this in his account of the plague of Athens (around 430 BCE, again in 429, and again in 427 BCE). This plague was caused by the military strategy of Athens, which was to rely on its far superior navy, and to retreat into the city when faced with a land-based army. This meant that a lot of people who lived in villages outside the city walls had to be accommodated, which resulted in overcrowding and the bad hygiene of the time becoming even worse. It's estimated that as many as two thirds of the entire Athenian population was wiped out in the plague.

China: In ancient China also this theory of miasma took hold. It was known as a poisonous gas in China, and the Chinese went a step further to bring the environment in as another factor. Heat, particularly, was considered to be a contributing factor to miasma. They also felt that it was insect waste (yes, insect poo), that was the real cause of the poison gas! The Chinese believed the southern part of China to be infected with said poison gas, and thus southern China was avoided like the plague. In fact, criminals and disgraced officials were sent to live in southern China as punishment!

Europe: All the way until the late 1800s this theory of miasma was the prevalent one, and the many plagues that europe suffered were all considered to be caused by miasma. For example, the cholera epidemic in the 1850s that spread across London and Paris was one such example. People believed that they were being exposed to bad air from the river Thames and since the theory was about the air, no one suspected the water itself, which is how cholera spreads. Well almost everyone was fooled, but not John Snow (Game of Thrones fans will be sniggering right about now). John Snow was an English physician who would eventually be proven right about the cholera outbreak, and thanks to him, a lot of improvement was made in public health practices (especially in large cities), around the world.



John Snow helped England understand the importance of hygiene

Another superstition that was prevalent in western cultures was that the night air was somehow dangerous, and carried toxins. Another group of physicians believed that contagions were spread via human contact, but they had fewer famous people on their side. Perhaps the most famous believer of miasmatic night air was Florence Nightingale, the nurse who became famous in the Crimean war. She is known as the founder of modern nursing, and is also famous for being "The Lady with the Lamp", because she was always taking rounds in the night to check on wounded soldiers.

Of course, needless to say, this was all quite wrong, because it wasn't the actual air making people sick.

I CAN'T SEE YOU

It just wasn't possible to discover anything smaller than what the eye could see – or perhaps, anything smaller than what the eye could see with, say, a magnifying glass.

The existence of living things smaller than what the eye could see was not an alien concept to mankind. In fact, it was one of the ideas in Jainism, and dates back to the sixth century BCE. Of course Mahavira said there were tiny living things inside water, air, earth and fire, in a very alchemy type of way.

There is quite a dispute over who was the first to empirically discover microbes. For a long time it was believed that Antoine Philips van Leeuwenhoek, the Dutch scientist was the first to observe them using a microscope he built by himself in 1676. He is known by many as the father of microbiology because of the work he did.

Later it was discovered that Robert Hooke, an English polymath, had written about microscopic life in a book he published in 1665 titled Micrographia.

However, it was then discovered that Athanasius Kircher, a German polymath had published books which contained references to microbial life, and were published as early as 1645!

While we can never be sure of who was the first to actually observe microbial life, it was van Leeuwenhoek who refined the microscope by taking an interest in lens making, and catalogued what he found.

Antoine Philips van Leeuwenhoyek

I SEE YOU

Very soon after microbes were discovered, theories started coming in about what they might be responsible for, and of course, they were linked to disease, infections, and the reasons why food would rot. The biology world went microbe crazy for quite a while after that.

Thank Pasteur for vaccinations

Louis Pasteur: A French chemist and microbiologist, Pasteur was one of the principle reasons for the development of the germ theory of disease. This is the theory that many diseases are caused by microorganisms, which were called "germs" at the time, and sought to control the spread of these diseases by killing these germs off. The microorganisms that caused disease were classified as pathogens, and the diseases caused by these pathogens were known as infectious diseases. The theory was not new in itself, and was originally proposed by Girolamo Fracastoro in 1546, but were revitalised because of Pasteur's experiments and efforts. Pasteur is often also given the title of father of microbiology, and many believe he deserves the title more than van Leeuwenhoek. Pasteur was also the man behind vaccines and the Pasteurization of milk to make it last longer. His contributions have saved countless lives thus far. He was not without controversy though, and historians suggest that his notebooks contain details of how he was unethical in his trials, and even conducted human trials and gave untested vaccines to children!

Robert Koch: This German microbiologist is known as the father of bacteriology, and was just as influential as Pasteur in popularising the forgotten Germ theory of Disease. He was responsible for identifying the pathogens of anthrax, cholera and tuberculosis. He

Koch's four postulates are used even today

also came up with the technique of linking microorganisms to diseases, using a method that we now know as Koch's postulates. His four postulates are: 1. The organism should always be present in every case of the disease, 2. The organism should be isolated from an infected host and grown in culture, 3. Samples taken from this culture should be taken and used to infect a healthy host, 4. Once the inoculated host is infected and falls sick, a sample of the organism should be taken and isolated, and should be identical to the organism found in the first infected animal. If all four of these conditions were met, it was surmised that the organism was indeed the cause of the disease. ■

Microbes

Understanding the different types of microbes that exist

Earth is overrun with microbes. Thus far, wherever we've looked, we've found them. And we mean everywhere! Almost a KM under the ground in Antartica? There they are. In the Mariana Trench – the deepest part of the ocean and the lowest land surface on Earth – they're thriving there. Inside hot springs, inside rocks, inside the earth as far as we've dug, in the atmosphere, in space surrounding the Earth, in every natural water body, salt water or otherwise... you name a place that we could stick equipment into to search for them, and there they are.

In the previous chapter you read about the history of their discovery and a very brief explanation of their evolution and when they showed up in the fossil record. Thankfully, we know a lot about them now, and certainly much more than the likes of Pasteur and Koch could ever know. We will get to classifications of microbes later, for now we're going to look at how we define them in the broadest sense first.

If we use terms you don't know, or that we haven't mentioned before, don't worry we will explain them in the chapters that follow this one.

ALWAYS SINGLE

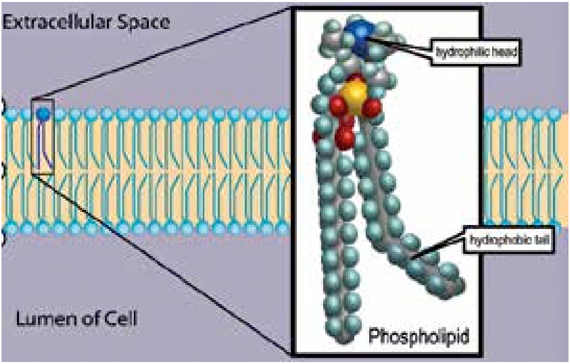
Single celled organisms are almost always microscopic, and are called unicellular organisms. Bacteria, archaea, protozoa, single-celled algae and unicellular fungi all make up the unicellular family.

It is thought that the oldest organisms on the planet, and the first "life" that ever existed was unicellular. Although there are examples of non-cellular life even today, the generally accepted definition of "life" is something that has a cell structure as a way of identifying it as an individual organism. Plus, being cellular in nature means that the organism can reproduce in some way, which is another requirement for us to consider an organism to be "alive".

It is thought that about 3.8 billion years ago RNA-based protocells (primitive cells) could have existed, and although it is not clear if they could be termed "alive", the hypothesis is that they were self-replicating by being part of an organic chemical reaction – perhaps even acting as catalysts for the chemical reactions.

It's obvious that natural selection would favour anything that had a cell wall, because a cell wall would isolate the chemical reaction from the "outside" world. This means it could prevent dilution of the chemicals, and obviously localise the reaction, making it more efficient, as well as faster. Perhaps this is why cell structures are, by far, the preferred blueprint for all life on Earth.

An example that we can see happen even today in labs is to observe how phospholipids behave when inserted into a water-



Phospholipids are an automatic choice to form cell walls because of their design

rich environment or solvent. Lipids are basically molecules of fat and can be found in various forms. Phospholipids are a class of lipids that are used by nature to build almost all cell membranes. Whether it's a bacteria or a human cell, the membrane is built using mainly phospholipids. Why is that the case? This is because they are amphiphilic – which means that they love both water-based as well as fat-based solutions. When we say "love" we really mean that phospholipids are molecules that have a surface that has an affinity to water, and another surface that has an affinity for other lipids.

Drop a bunch of molecules of phospholipids into water, and they will quickly join up to form a kind of wall between the water and their fat-loving surfaces. This is because the water-loving side orients towards the water, obviously, and then the lipid-loving sides join with other phospholipid molecules to form a chain, and then eventually something that looks like a cell wall. We are being flippant, of course, in this description, and it's taken decades of painstaking work by hundreds of biologists to arrive at what we just threw at you in a paragraph, but that's pretty much all that science is... a tremendous amount of work for every inch of progress.

Honestly, we don't know how life got started, but the clues we get from how things such as phospholipids behave certainly gives us some data that we can use to make educated guesses about our origins.

A popular hypothesis is that phospholipids might predate life, and perhaps early RNA life invaded a phospholipid cell and was able to thrive, which it then learnt to use and then how to replicate.

The oldest fossils and signs of life suggest a unicellular cyanobacteria like form We will get to details about the different types of unicellular organisms in later chapters.

ALL THE CELLS!

Multicellular organisms are ones that consist of two or more cells. Humans, elephants, blue whales, etc, are also all multicellular organisms. However, only a few are microscopic.

Based on modern data and DNA evidence, it is thought that many branches of multicellularity have evolved ever since life began. Across the different types of life (Prokaryotes and Eukaryotes), there's evidence to suggest that unicellular life mutated into multicellular life about 46 times in the past four or so billion years.

Complex multicellular life, however, seems to be limited to eukaryotes – of which we are also a part. However, complex multicellular life brings in the problem of sexual reproduction,

Hermaphroditus, the "son" of Hermes and Aphrodite (herm+aphrodite)

which is again, one more thing we don't know too much about.

The problem with sexual reproduction is that we have not found an explanation as to why these complex organisms evolved a technique to use germ cells (sperm and egg) to reproduce. We haven't been able to identify how this process could have got started, and it obviously couldn't be something a single cell or single organism with one gender could have done, because sexual reproduction needs two sexes to procreate. Perhaps hermaphrodites are the missing link between asexual and sexual organisms. Hermaphrodites are organisms that have the reproductive organs and capability of both male and female sexes. Snails, slugs, clownfish, earthworms, etc., and of course, all plants are hermaphrodites.

There are quite a few theories about why, or rather, how multicellular organisms evolved. All of the evidence tells us that single celled organisms were ruling the earth for a very long time, and then suddenly there seemed to be an explosion of multicellular life, which implies that some really hot and new recipe for life evolved which just started a crazy chain reaction.

The Syncytial theory: This theory suggests that a single cell organism could have had a fault when dividing to reproduce asexually, and perhaps only the nuclei split several times inside the single cell. Then, membranes could have formed around each nucleus, and the end result would be a multicellular organism with one large cell wall. This theory (hypothesis, actually) is supported by evidence in some protists, notably slime molds, which have several nuclei in a single cell. Of course we haven't seen a single cell evolve into multicellular life in front of us, so it remains a hypothesis.

The Symbiotic theory: This is a story of true prehistoric brotherhood... Imagine different single cell species working together in harmony, and being dependent on each other for survival. Eventually they would be so dependent that they couldn't live without one another, and in a tale that rivals Hollywood love stories, they would eventually merge and become one... binding their destinies and those of all of their descendants together, forever. <Insert romantic / emotional Hans Zimmer musical composition here> However, there's just one problem this theory has not been able to explain, and that is how the two (or more) organisms' DNA could have fused into one. This theory is also supported by evidence – the symbiotic relation between clownfish and sea anemones, for example, or the different organisms that make up a composite lichen. In both cases, though, while one going extinct would almost certainly spell doom for the other(s), they're always independent and reproduce on their own, without sharing DNA in anyway.

The Colonial theory: The colonial theory is one of the older theories, and is also backed by evidence in nature. It was put forth by Ernst Haeckel, a German biologist, in 1874. The idea is that many organisms of the same species would have come together to form a large colony. Eventually, some of the organisms of this colony would change in order to be more specialised for their role. A simple example is to imagine a ball of protists. Only the outer layer of protists would use their flagella (tail like things) to manoeuvre, while the inner layers would not. In this way multicellular life could have evolved from colonies of one species. In nature, we see this happening in several species. Some amoebae group together to form a colony when survival demands it, and move as a group to a new location. Some other

Many amoeba coming together to form a slug (pseudoplasmodium)

protists group together and only a few reproduce, while the rest take on other "tasks".

To elaborate on the amoebae example: Dictyostelium is an amoeba that lives most of it's life as a unicellular organism, and will do that for as long as the food supply is good in whatever area it lives in. It even divides to reproduce asexually, and the newly formed amoeba will go off on its own.

Once the food supply starts dwindling and the amoebae need to migrate to a new food source, they will clump together with other amoebae, form a kind of a slug and they work together to move to new locations faster than they could have alone. This isn't just another story of a selfish interest group, because we soon see altruism on display, and as you know, altruism is usually considered to be something only higher life forms do. Once the slug decides to reproduce, it forms a fruiting body, which means that it forms a base, a stem, and at the very top spores form to be able to migrate to better locations. What's interesting is that the cells (individual amoebae, which were fending for themselves just a short time ago) form the base and the stem of the fruiting body, which is an act of sacrifice because they die. Only a few amoebae rise to the top of the fruiting body to become spores. Thus, the genetic individuality of the thousands of amoebae below are wiped out when they die, so as to protect some of the colony. This is so much like how we humans behave, and these things are just unicellular amoebae with no brains... go figure!

It is obvious that the colonial theory is one of the strongest we have for how unicellular creatures evolved into multicellular ones. There are more though...

Other theories: There are other theories as well, some arrived at by genome and DNA mapping which suggest a mutation in a single genetic molecule called the guanylate kinase protein interaction domain (GK-PID) could allow organisms to become multicellular. Then there is the theory about viruses, which is very interesting, because it suggests that many cells have genes that are borrowed from viruses, and this perhaps enabled them to change from one type of cell to another because of the additional genes. In fact, discoveries made in the last decade suggest that all cellular fusion proteins come from viruses. This is still being researched, but if correct, multicellular life, all of it, would only have been possible because a virus infected the DNA of a unicellular organism... remember what Agent Smith says in the Matrix? "Human beings are a disease, a cancer of this planet." Turns out all multicellular life might very well be...

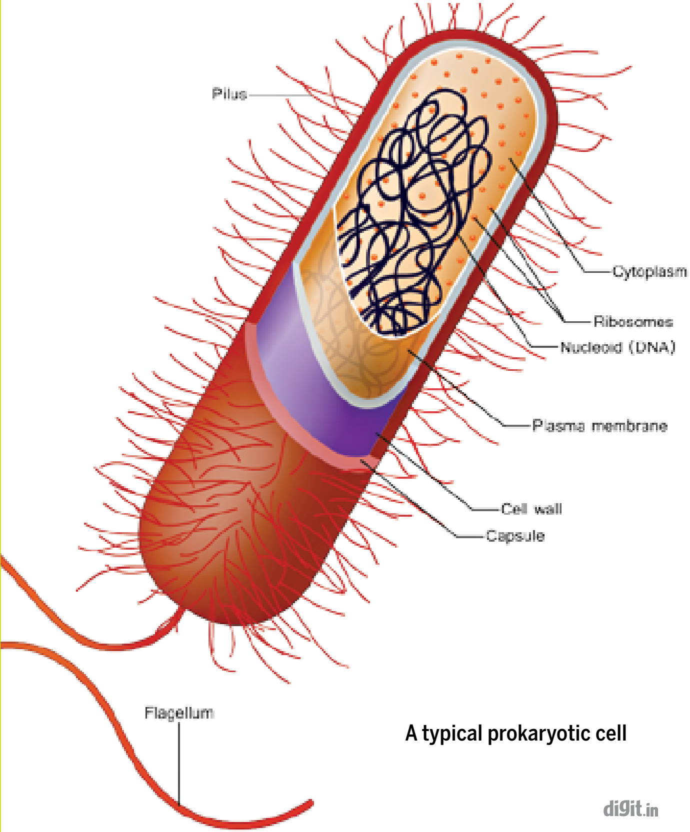
Now it's time to look at the various classifications of life, especially microscopic life. ■

Prokaryotes

So what are they anyway?

Prokaryotes are unicellular organisms that have just a cell wall with all other cellular material just located freely in the cytoplasm. Prokaryotes contain no defined nucleus, or mitochondrion, or really any membrane enclosed defining feature other than the cell wall and the flagellum. The genetic "stuff" just floats around inside the cell wall, and you can think of them as a water balloon with a tail.

The term prokaryote is, obviously, Greek in origin, where "pro" means before and karyon means nut, or kernel, to be more precise. Of course, the "nut" or "kernel" here would be the nuclei that is found in the other kind of life – Eukaryotes. Thus, the name literally means "before the nut", indicating that the prokaryotes are older than the Eukaryotes, which is precise as per the current understanding of biological evolution. Prokaryotes are about 2 billion years older than their "nut" containing counterparts.



A typical prokaryotic cell

Prokaryotes can be further divided into two main groups – Archaea and bacteria, and we will look at them individually soon. Since archaea and bacteria are considered a different species, some say that the only meaning for the term prokaryote is "not a Eukaryote".

Overall, the easiest way to identify a prokaryote under a powerful microscope would be to look for some identifying features, such as:

Flagellum: This is a long tail-like appendage that the cell uses to move about. The The flagellum is flailed about at one end to move in the opposite direction.

Cell membrane and wall: A surrounding membrane that encloses the cytoplasm, sometimes found along with a wall surrounding the membrane which gives the organism its shape and distinguishes it from the rest of the background solution.

Cytoplasm: The substance that everything inside the cell wall and membrane is contained in. It's a gel like substance that holds the DNA and other genetic material of the cell.

Nucleoid: Although prokaryotes don't have well defined nuclei, they do have a nucleoid which is basically the single DNA molecule of the bacteria.

Ribosome: Ribosomes look like little dots or blobs, and are basically where proteins are made. They receive the messages from the DNA via the mRNA (messenger RNA), and use amino acids to make proteins. Think of mRNA as the recipe, amino acids as the ingredients and proteins as the finished meal, then ribosomes are the kitchen.

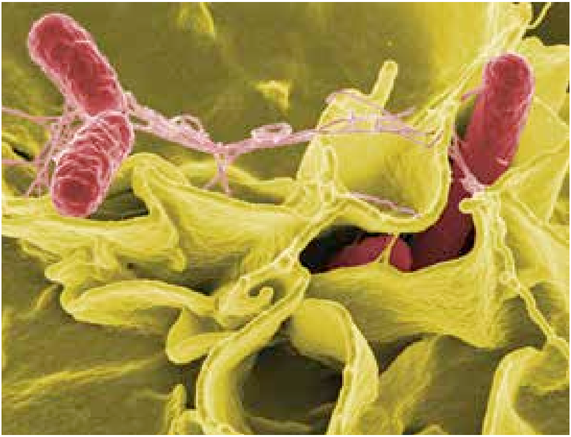
Prokaryotes also come in various shapes, with most being either spherical, rod-like, spiral-shaped and comma-shaped, though a few can be shaped like squares!

BACTERIA EVERYWHERE!

Bacteria are amongst the oldest living organisms on our planet, and are typically 1 to 10 microns (micrometers) large. To illustrate how small this really is, consider that the thickness of a human hair is typically around 50 to 100 microns. They're so small that a gram of soil usually contains an estimated 40 million bacterial cells!

Bacteria are almost everywhere. All around us, on us, in us, in every tissue and organ, (not in our blood stream), in the soil, in the air, water, under the earth, in rocks, at high altitudes, in hot or cold places... But what are they?

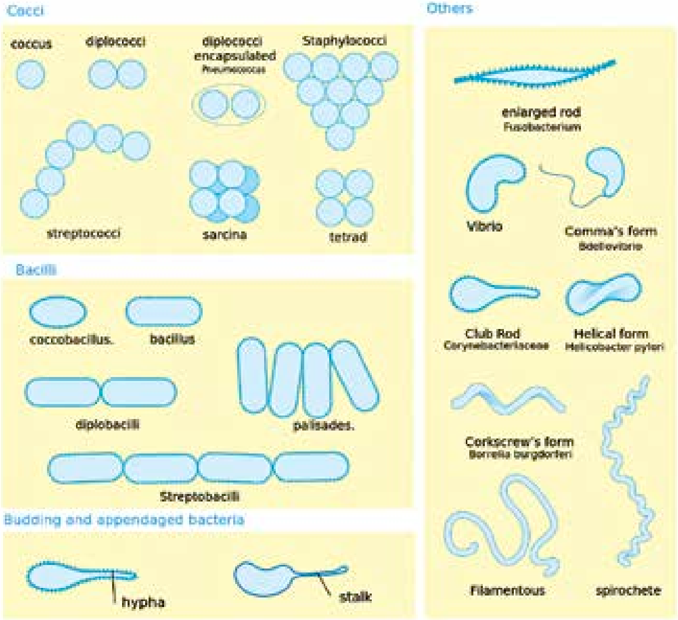
Most of the life on earth is bacterial. And we don't mean it in terms of numbers, which is obvious, as there are an estimated 5×10^{30} bacteria on Earth, but they also account for the majority of the biomass on the planet. The bacteria weigh more than all of the plants and animals on the planet combined!



Salmonella attacking human cells (false colour image)

Although bacteria come in many shapes and sizes, the term bacteria is formed from the Latin and Greek words for staff or cane, because it just so happens that the first ones to be observed were rod-shaped bacteria. We don't know what they would have been called if the first ones that were noticed were comma shaped ones...

It is thought that bacteria evolved from whatever was the first unicellular organisms to show up on earth about 4 billion years



Morphologies of bacteria

ago. We can only trace them back to a universal common ancestor using DNA, which is needless to say, a very hard task. Since they are so small and soft, there are no fossils of individual bacteria, or for that matter, their predecessors, which makes figuring out their evolution a game of educated guessing.

In biology, the many shapes of organisms are called morphology, and bacteria have many morphologies, which we mentioned before as well – spherical, rod-shaped, comma and spiral, but these are merely a simplification. There are star shaped, rectangle-shaped and helical shaped bacteria as well.

Not all bacteria are microscopic though, and some, such as Thiomargarita namibiensis (found in Namibia) can be 0.3 mm long – or basically visible at close range with the human eye!

The smallest bacteria are usually about the size of the largest viruses, which is about 0.3 microns (0.0003 mm, or 1000 times smaller than the largest bacteria mentioned before). We are finding bacteria that are even smaller all the time, and we haven't discovered most bacterial species that live on our planet, so neither the largest nor the smallest bacteria measurements are set in stone.

The bacterial cell structure is something we've discussed in brief before as well, but basically it's a cell structure that's pretty simplistic.

The cell membrane holds the cytoplasm, but is permeable, which means it allows the exchange of nutrients, while the cell wall is tougher and "seals off" the organism from the surrounding. With just a cell membrane and no cell wall, bacteria wouldn't be able to exist, because of turgor pressure. Turgor pressure is basically the pressure caused by osmotic flow of water from an area of low concentration to high concentration. This pressure (or turgidity) is what gives plant cells their stiffness, and allows them to remain rigid. For bacteria, not having a cell wall would reduce the concentration of their cytoplasm, and make it very hard (if not impossible) for them to survive.

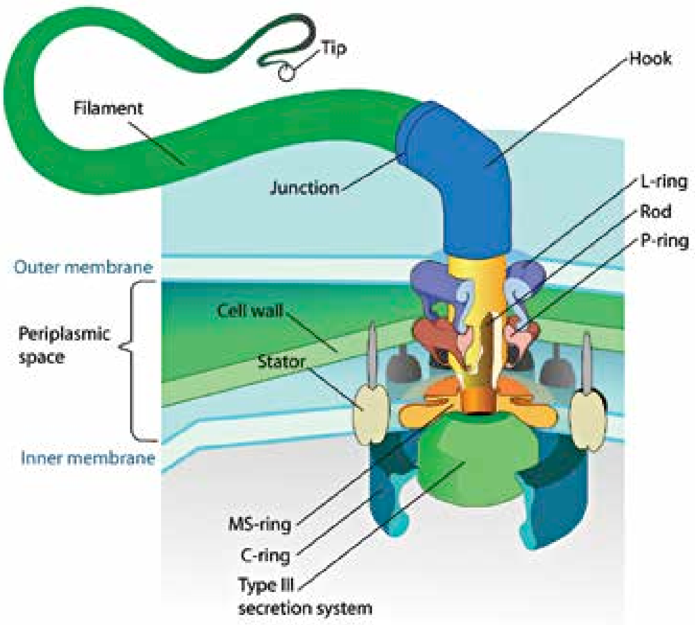
Many bacteria also have fimbriae or pili, which are protein tubes that extend from the outer membrane of the bacteria, and end up looking like hair, for lack of a better description. These fimbriae or pili help a bacterium attach itself to surfaces or other bacteria. Fimbriae and pili are different structures, and are not two names for the same structure, though both have some similarities in looks and uses. Pili are usually longer, are less numerous than fimbriae, and pili are used to grab on to other bacteria for mating purposes, or also to attach to surfaces. Note that bacteria don't "mate" like animals do, as it has no germ cells; instead, two bacteria will directly exchange genetic information by attaching themselves together and exchanging genes.

The last obvious external feature of a bacterium cell is the flagellum. In Latin, the word literally means whip, and that's exactly how the flagellum functions. The main function of the flagellum is to aid movement (locomotion), but it also plays an important function as a kind of early warning system. Because the flagellum extends far from the bacterium's cell (body?) it is able to sense chemicals or temperature before they come in contact with the bacterium itself.

On the inside, a bacterium is a rather simple structure – relatively speaking of course. There's a gel-like solution called the cytoplasm that is akin to the bacteria's "blood" and "organs", which holds all of the other "body parts" of the bacteria. We use these words merely as a way of illustration of course, and if you are a biology major, our sincere apologies, don't write in angry letters... think of it as poetic license...

There is no nucleus in a bacterium, as we've mentioned before, and thus the DNA floats freely inside the cytoplasm. This DNA is tightly coiled and often appears circular. This is called DNA supercoiling, and it is important because it allows the DNA to be tightly packed into a much smaller space, which is why bacteria can be really small.

In addition to the DNA, there are small chunks of DNA called plasmids that are found in the cytoplasm. Although not exclusive to bacteria, as plasmids are found in some archaea and eukaryotes as well, it is still mostly a bacteria trait to have these plasmids. Plasmids



A closer look at the flagellum

are really useful to bacteria, because they are like little circular balls of double-stranded DNA floating about in the cytoplasm. What do they do? They store additional information apart from the basic genetic code. This can include, for example, the antibiotic resistance that the bacterium or its ancestor built up. To illustrate it for us geeks, think of the main DNA strand as the operating system, and the plasmids are installed software that add functionality to the system! Although plasmids do the same job as the main DNA molecule, they're not considered "alive" as the bacteria itself is, and are categorised along with viruses as nonliving genetic material.

Ribosomes we have mentioned earlier in this , so we will not go into any further detail about them.

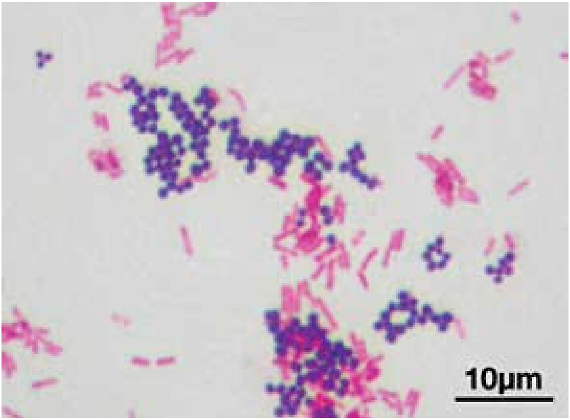
All these are not even close to a detailed list of bacterial components, and given the thickness of most biology textbooks, you can understand why this is merely a primer. Let's just say that if you are interested in learning more about just bacteria, and nothing else, you could spend the rest of your life reading and learning new things about them every day!

Gram staining: Many of you would have heard about gram positive or gram negative bacteria, and wondered what on earth they were. Well, we're going to attempt a simpler explanation. Bacteria are sorted into two different types, based on the composition of their cell walls. One of the first things that are done with a sample of bacteria is gram staining. The process is named after Hans Christian Gram, a Danish biologist who came up with the technique.

This process involves treating the sample with four different liquids. First, crystal violet dye is added to the specimen. Next, iodine is added, which reacts with the crystal violet dye, trapping it in any cell that has absorbed it. Then the specimen is washed with alcohol (ethanol or acetone), and finally a safranin stain is added.

The idea here is to look for bacteria that have a large amount of peptidoglycan accessible in their cell walls, which are termed Gram positive, and absorb the crystal violet dye. If they don't absorb it, they are termed as Gram negative. Gram negative bacteria also have peptidoglycan but it is covered with a thick layer of fats (lipids), which doesn't allow the dye in. The more peptidoglycan that's in a cell wall, the more a bacterium will absorb, and the less resistant it will be to antibiotics.

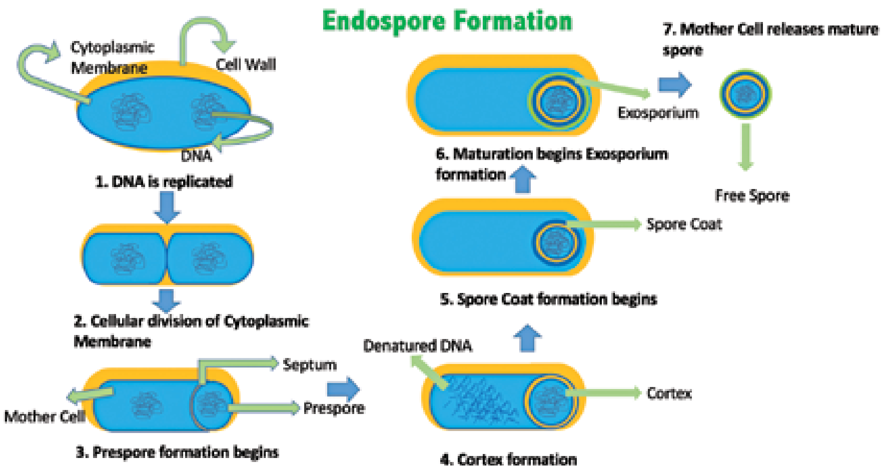
Gram positive bacteria absorb both the violet and the safranin stains, but since the violet is a lot darker than the light pink of the safranin, it is not noticeable. Gram negative bacteria don't absorb the crystal violet dye as they are protected by the lipid layer, which does absorb the safranin stain. This is why the first test done by a medical lab on a bacterial infection sample is to figure out whether it is gram negative or positive. If it's a sample of yours, or a loved one, you can breathe easier when you hear that it is a gram positive



Violet/purple are Gram positive, and pink are Gram negative bacteria

bacteria, because those are easier to kill off with a full course of cheap antibiotics. If it's gram negative, your bills are going to be pretty high, and your immune system will be worked a lot harder.

Some gram positive bacteria are also able to form endospores. An endospore is like a hardy structure that a bacteria remains dormant inside of until the conditions are right for survival again. Endospores appear dead for all practical purposes, and can survive high UV



How endospores form

radiation, gamma radiation, most chemicals, disinfectants, heat and cold, and even extreme dryness (desiccation). Endospores can, in theory, survive millions of years, and can withstand the harshness of space. We have found bacterial spore on the earth that are 40 million years old! One of the diseases that is caused by bacterial spores re-activating inside a human body is Tetanus, caused by spores of Clostridium tetani. Endospores are what make the theory of panspermia possible – it's a theory that life didn't develop on earth, but somewhere out there in space on another long dead planet, or even Mars, and arrived on Earth in endospore form.

Food: Bacteria are also classified according to the source of their energy. For example, a phototroph is a bacteria that uses light as a source of energy. In nature this is obviously sunlight. Similarly, bacteria that "eats" nonliving chemicals is called a lithotroph (energy source is inorganic compounds), and bacteria that derives energy from organic compounds are called organotrophs.

Reproduction: Bacteria reproduce asexually and are clonal – they bestow identical copies of their genes to their offspring, or rather, they produce clones instead of offspring, as there is only one "parent". Of course mutations happen, and bacteria exchange information directly as well, as we've mentioned earlier.

War and peace: Some bacteria depend on each other for survival, and are known as mutualists. Others kill and "eat" different types of bacteria by swarming and surrounding and absorbing them, and are known as predatory bacteria. Pathogenic bacteria, however, infect other bacteria and eventually cause their death. Most bacterial infections in humans are caused by pathogenic bacteria.

Some interesting fact about bacteria below *:

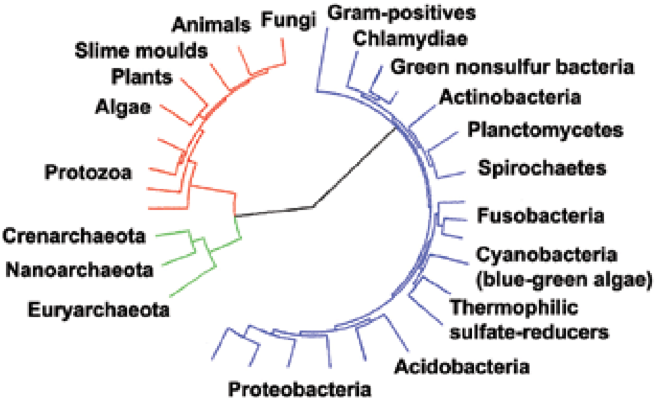
- The bacteria in our body weighs about 2 kg
- There are more bacteria in your mouth than people on earth
- Your mobile phone has up to 20 times more bacteria on it than a toilet door handle
- Sticking with toilets; the average office desk has more bacteria on it than a commode in a toilet
- Chocolate actually kills bacteria in your mouth, and helps protect your teeth
- A couple kissing can exchange up to a billion bacteria per kiss
- Bacteria can "see" and use their entire bodies as an eyeball

** Source: factslides.com*

WAITER! THERE'S AN ARCHAEA IN MY PRIMORDIAL SOUP!

Externally, archaea look a lot like bacteria, and were thought to be bacteria for a long time. Archaea and bacteria are pretty much similar sized, but in terms of genetics, they have genes more closely related to eukaryotes than bacteria.

They were considered extremophiles because they were found in some very interesting places such as hot springs and very salty water bodies. However, as we have improved our method of looking for them, we now find them in many more places – including in soil, inside human's colons, oceans, etc. They are



Bacteria are the most diverse. Here archaea are green, eukaryotes are red and bacteria are blue.

shaped like bacteria for the most part, but sometimes also have odd shapes such as squares!

Archaea are thought to be amongst the oldest living things, and though some would consider them to be the oldest, there are other theories that suggest that bacteria, archaea and Eukaryotes all have a common ancestor that isn't around anymore, and didn't have a cell structure. Another theory is that bacteria are older than archaea, and that archaea might have developed as a result of antibiotic resistance to bacteria. This hypothesis is supported by the fact that most bacterial antibiotics attack other bacteria in exactly the places where archaea differ from bacteria. It's also considered that the fact that a lot of archaea live in extreme environments suggests that they moved into niches where bacteria couldn't thrive, and perhaps did it in order to survive an onslaught by antibiotics.

The major reason why scientists stopped classifying archaea as bacteria was because of the difference in their RNA. It was only in 1977 when Carl Woese was able to develop a new method to break down RNA and classify it that it was realised that there were some prokaryotes that just had a very different RNA structure from bacteria. Woese called these microorganisms archaea.

Other differences between archaea and bacteria are:

- Archaea's cell walls don't contain peptidoglycan.

- Archaea have cell membranes that are not made of phospolipids, but instead are made of glycerol-ether lipids
- Most life is built around ester bonds (for simplicity, imagine this to be a chemical bond that has a carbon atom double-bonded to an oxygen atom – ~C=O), but archaea are built around ether bonds (the oxygen is single bonded to two carbon atoms – ~C-O-C~). Here "~" merely symbolises that there are more bonds to those atoms.
- This ether bond (found in archaea) is also much more stable, and thus, reacts less to other chemicals, and can withstand much more temperature, etc., which is what gives archaea their extremophile ability.
- Some archaea are able to obtain energy from inorganic compounds such as sulfur or ammonia.
- Archaea can also be phototrophs (using sunlight for energy), but unlike other life, they don't use sunlight to photosynthesize and form oxygen, but instead use it to break down inorganic compounds.

Archaea are very important to the environment, and some of them, help the environment and some harm it (from the human perspective of course).

Nitrogen cycle: The most important contribution by micro-organisms is to the nitrogen cycle. Nitrogen is the most prevalent gas in our atmosphere, but it's pretty much useless to most plants and animals in that form. In order to be of use to life on earth, nitrogen must undergo a four step cycle, which involves fixation, ammonification, nitrification and then denitrification.

The first step – fixation – is where bacteria and archaea come in. Nitrogen from the atmosphere needs to be "fixed" in order to be of use to the biosphere of earth. Prokaryotes do this by com-

The Morning Glory hot spring in Yellowstone National Park and the bright colours caused by the archaea that live there

bining nitrogen gas with hydrogen to form ammonia, which is then converted to other compounds by the prokaryotes. Once in this compound form, the nitrogen is suddenly usable by, say, plants as fertiliser, and this nitrogen is then passed on to herbivores which eat the plants, and then to carnivores that eat the herbivores.

When plants or animals die, or when they excrete waste, the nitrogen is in organic form. This is then converted to ammonium again by bacteria. The next step, nitrification, is the oxidation and conversion of ammonia to nitrates (NO_3^-) or nitrites (NO_2^-). This is very important because ammonia is poisonous for plants.

The final step, denitrification is what completes the cycle, and converts the nitrates back to nitrogen gas, and this is performed by different types of prokaryotes.

It's pretty plain to see that without bacteria and archaea, nothing on earth would survive very long. The plants would be the first to die off in a prokaryote-free world, and then the rest of us would go the way of the dodo. ■

Eukaryotes

Pretty much everything we consider to be life

As we've mentioned in previous chapters, the major difference between eukaryotes and prokaryotes is the nucleus that is in the eukaryotic cell. There are other organelles such as the mitochondria, golgi apparatus', lysosomes, etc., but it's really the nucleus that defines eukaryotes. The name is from the Greek words Eu (true) and karyon (kernel).

Although most eukaryotic cells reproduce asexually using mitosis (splitting of the nucleus), many also reproduce using meiosis, which is sexual reproduction. The process of meiosis involves a single cell splitting twice (first into two and then into four), producing four cells with half the number of DNA as the parent. These four daughter cells are thus gametes, and fuse with other gametes to form a whole cell with new genetic information from two parents. This is how everything from plants to us reproduce.

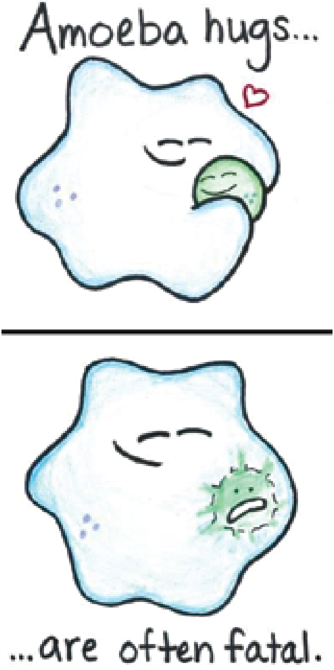
In terms of numbers of individual organisms, prokaryotes outnumber eukaryotes by orders of magnitude, but given the

All these are eukaryotes!

eukaryotes larger sized and mostly multicellular nature, the ratio of the mass of eukaryotes to prokaryotes is thought to be close to 1:1. This is because every human, elephant, whale, tree, plant, fish, etc., on the planet is a eukaryote, and that counts for a lot of mass per individual as compared to bacteria or archaea. But enough about us and whales, this is all about microscopic life!

The eukaryotic cell is usually much larger than a prokaryotic one, and, as we've mentioned many times before, contains organelles. They are thought to have evolved about 2 billion years ago. Many eukaryotic cells "eat" their food by invaginating the cell membrane around the food. Invaginating is the process by which the cell membrane folds itself inwards to form a cavity, and once the food is in the cavity the extremities close off to prevent escape and seal around the food. Think of it like opening your mouth when you see food, and then closing your mouth around it, except since cells don't have mouths, they warp their cell walls around food to eat.

It is this process of invagination for food that makes some biologists advocate it as the method by which eukaryotes formed in the first place. The assumption is that genetic materials being ingested by invagination led to the organelles of a typical eukaryotic cell being formed. This would have been a very significant development in the history of life on our planet, because almost all multi-cellular life, and certainly all complex life on earth is eukaryotic.



Just invaginating...

There are a couple of hypotheses about how they evolved, and we'll quickly look at them now.

Chimeric: This hypothesis says that we started off with two prokaryotes – archaeon and a bacterium – and these fused or merged, and formed a eukaryotic cell. This would explain why eukaryotes have similarities with both types of prokaryotes. This is a more accepted hypothesis.

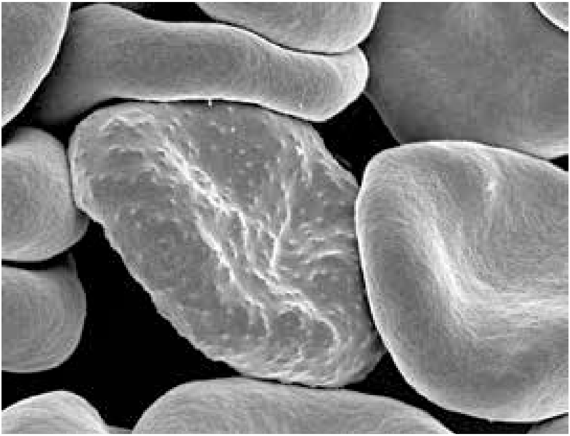
Autogenous: This is the hypothesis that we mentioned before, about a prokaryote invaginating often and forming the endomembrane system (the inside of a eukaryotic cell).

PROTIST

A protist is pretty much a group of "others". It's any sort of eukaryotic organism that isn't already classified as a fungus, plant or animal. If you really insist on being given a definition, a protist would be a unicellular eukaryote that does not form tissues.

Like other eukaryotes, protists also reproduce by either dividing or doing so sexually. They get energy from either the sun (algae) or from organic compounds (amoebae, for example).

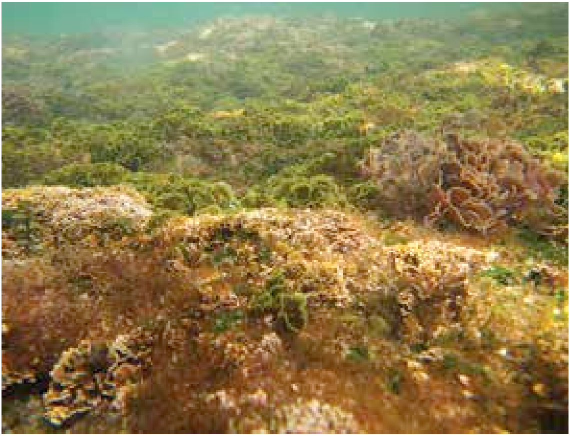
Protists need liquid water to survive, and as a result are mostly found in the ocean. They're not always far out at sea though, and some protists have a very real effect on our lives. Some can, in fact,



A red blood cell infected with malaria

be parasites and cause some serious harm. Malaria is one example of a protist caused disease – plasmodium is the culprit in this case.

Other diseases that protists are responsible for are sleeping sickness, amoebic dysentery and trichomoniasis. Sleeping sickness is malaria-like and transmitted by the tsetse fly in Africa. Trichomoniasis is a sexually transmitted disease that's not the most serious of STDs, but it can cause irritation in the genitals,



Algae off the east coast of Australia

which can increase the risk of contracting or transmitting more serious diseases such as HIV.

They're not all bad though, because most protists are algae, and estimates suggest that of all the photosynthesis that happens on earth, algae are responsible for about half that. We don't need to tell you what happens if the production of oxygen was suddenly halved across the planet...

Protists also help decompose once living things, and play an important role in recycling nutrients. They also keep the amount of bacteria in check, and thus, maintain balance in nature.

Not only are protists useful, there's new evidence that protists exhibit memory, and can even calculate the shortest distance between two points! Don't believe us? Flip to the back page of this book and follow the link...

I'M A FUN-GI

A fungus is a eukaryote, and can be either unicellular or multicellular. Yeasts and molds are examples of unicellular fungi, while mushrooms are an example of multicellular fungi.

Fungi are heterotrophs, which means they use carbon from complex organic substances to grow – animals (even humans) are heterotrophs. What this basically means is that we eat other living things to be able to survive – whether plant or animal, we are eating organisms, and so are fungi. Unlike the other microorganisms we've spoken about thus far, fungi have Chitin $(C8H13O5N)n$ in their cell walls – this is the same stuff that makes up the shells of crabs and other crustaceans, and the scales of fish.

Fungi's most important contribution to the biosystem is decomposition, and they grow in order to move. Though some

Nothing like a collage of fungi to whet your appetite!

fungi are able to create spores to travel through the air or water, most fungi move by growing and eating their way across everything. Once thought to be plants, fungus are actually genetically closer to animals than plants.

Can't have bread or beer without yeast

Without unicellular fungus such as yeast (especially yeast), we'd have no bread because it's used as a leavening agent. Well, truth be told we could find another way to fill dough with air when baking it, so maybe we'd eventually figure out bread... but would we have beer? An important part of the production of beer is the fermentation process, which is caused by a fungus. Given that some amongst us cannot function without a beer or nine every once in awhile, we wonder if humanity would ever have been the same if we didn't have beer. The Egyptians were the first to use it, and look at what they accomplished! A little beer goes a long way – and builds pyramids as well, apparently!

There are an estimated 5 million species of fungi, out of which we know and have classified less than five percent. Needless to say, there's a lot of discovering we still have to do... Fungi also play an important role in nutrient cycling (we mentioned the nitrogen cycle earlier), and as chief decomposers of earth, they're super important. (Chief Decomposition Officer - CDO?).

They're not all good though, because fungi can act like parasites, especially haranguing plants, but also afflict humans and other animals. In humans, common fungal infections include ringworm, athlete's foot, candidiasis and also can cause allergies or allergic reactions. Of course, we all know that some mushrooms are poisonous to the point of being deadly (capable of killing with toxins), and thus, fungi can sometimes have varying degrees of toxicity. Of course this still doesn't stop us humans from enjoying the edible mushrooms and fungi in what is often fine dining. Order a plate of truffles the next time you see it on the menu in

Cross section of a truffle

a fine dining restaurant, and you will see what we mean – they're supposedly very tasty, but your wallet might die.

Apart from this, fungi are also used to develop new medications, are used as pest control in many gardens, find their way into many foods, especially all dough based products such as pizza or bread, and also used by industries to produce a wide variety of chemicals... some fungi are used by people to get high because they can cause hallucinations in humans – they're sometimes called magic mushrooms...

WATER BEAR DON'T CARE!

No oxygen or air, water bear don't care! *(http://dgit.in/WtrBr)*

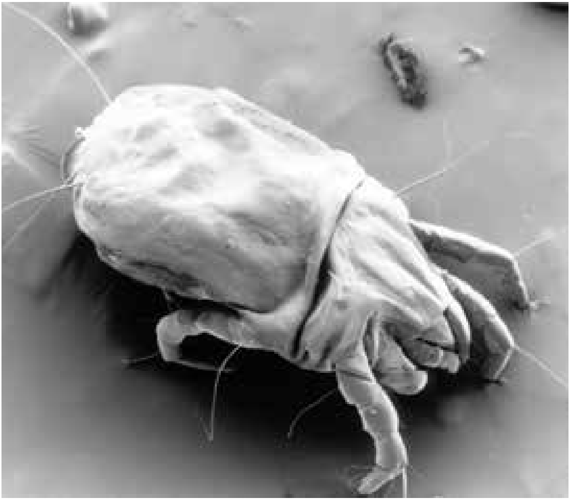
Forgive us, but we can't get that darn song out of our heads and don't want to suffer alone.

Tardigrades are extremophiles and can survive boiling water (actually even 150 degrees C), near absolute zero temperatures of space, high pressures radiation and can live without food or water for decades at a time!

It's not just the tardigrades that are small, in fact, at an average of 0.5 mm they're relatively large compared to other micro-animals.

Most common are dust mites, which feed on dead skin that flakes off us every day, but the problem is that their fecal matter causes allergies and even asthma. They're about 0.2 mm long, and are nearly impossible to spot with the naked eye, but there are hundreds, if not thousands all over your home.

Other examples are animal plankton, which are a collection of organisms that float in water (they usually don't swim). Plankton is really a collective term for bacteria, archaea, algae, protozoa

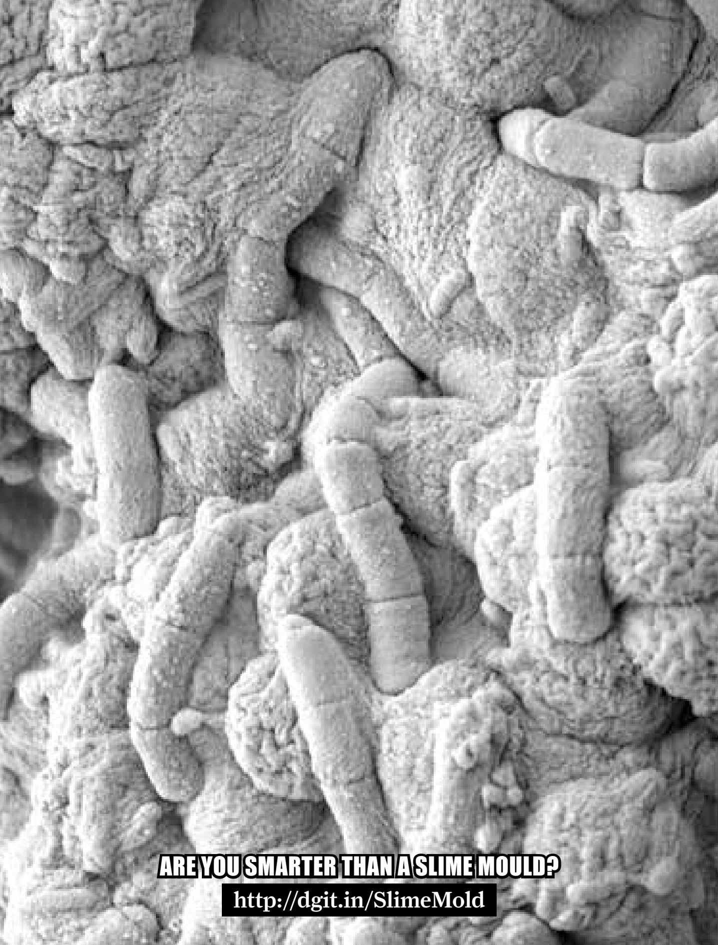


A female dust mite

and animals that are microscopic and float in water, which fish and whales feed on.

Sadly we've run out of space in this edition of dmystify, so we cannot go any deeper into microorganisms, and to be honest, we've barely scratched the surface! The aim of this dmystify, like all the others, however, is to give you a primer, and hopefully spark an interest so that you go online and look for more information, and get your much needed dose of science. We hope we've been able to get you interested in the world of the tiny, and hope that some of you will invest in a home microscope and enjoy exploring the little world we cannot see on our own.

As always, write in to *dmystify@digit.in* and send us your feedback. We love hearing from you. ■


ARE YOU SMARTER THAN A SLIME MOULD?
http://dgit.in/SlimeMold