The Echo

founder’s issue-2024

Special Section-
Puzzling discoveries in Science

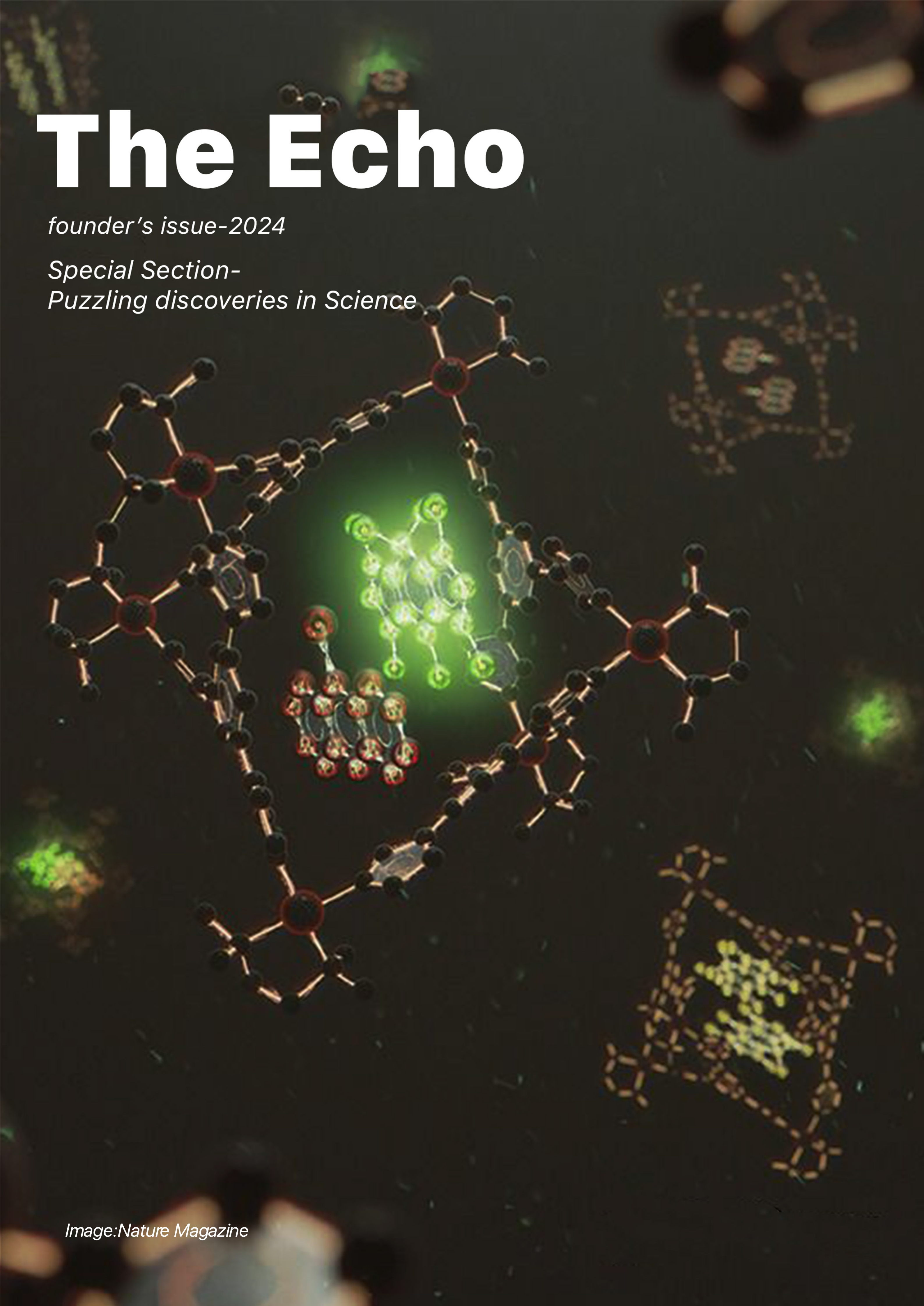

Image:Nature Magazine

The first article that I wrote for The Echo was an article on Gravitational Waves. This was back in the January of my D form, and I copy pasted the entire thing off of Wikipedia, woefully naive, unaware of the fact that others too, knew what Wikipedia was, and had probably read what was written on it, or that Turnitin even was a thing. To the best of my count, I wrote four, maybe five articles for The Echo before one finally got published in my B form.

I am not writing this to tell you or encourage you to plagiarise articles, but to tell you that even if you do not believe in yourself, never give up. As I flip through the pages of the last issue of The Echo that I will be a part of, all I can think about is how science has advanced over the years. In this founder's edition of The Echo, we explore a wide range of topics, from detecting deepfakes to atomic propulsion engines. The special section focuses on the discoveries that are taking place at the edge of Science. Here, we embark on a fascinating journey through topics such as Neutron degenerate matter and the Graviton to the discovery of light.

Finally, I'd like to express my sincere gratitude to my entire editorial board for their hard work and support. It would not have been possible to publish this issue without your help. It has been an honor to work with each and every one of you.

Signing off,

Aradhya Jain
Editor-in-Chief

Editorial Board

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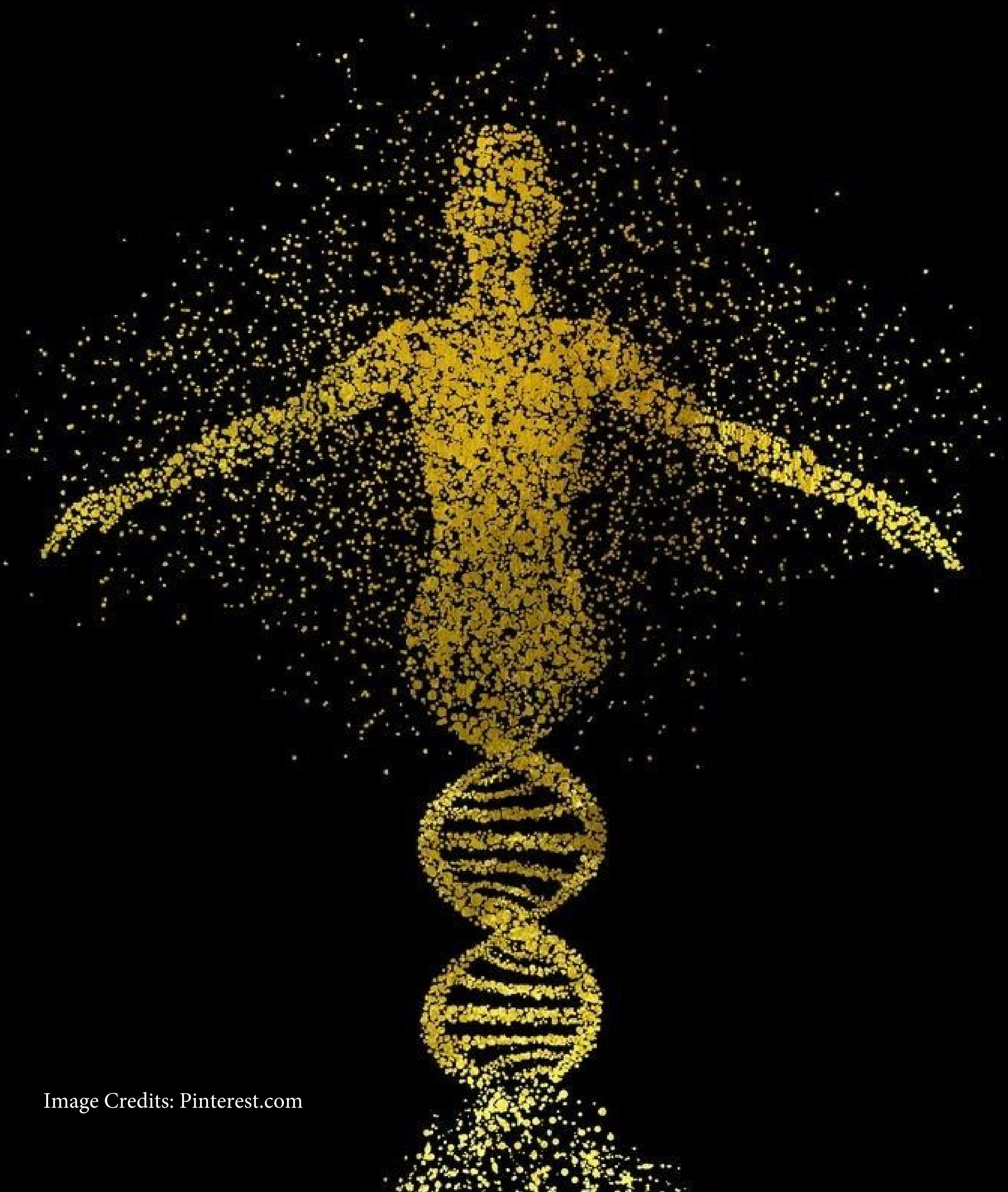
HUMAN CATALOGUES?

by Arnav Khaupude



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Imagine a young couple in the future, eagerly wanting to have a child. A DNA expert greets them and lays up a catalogue in front of them; do they want their child to be blonde or black-haired? Do they want a curly-haired child? Do they prefer large or small eyes for him/her? It is much beyond our current abilities to be able to choose how their child appears, but all of this and much more might be made possible by a DNA sequence known as CRISPR.

The discovery of Clustered Regularly Interspaced Short Palindromic Repeats, also known as CRISPR, marked a paradigm shift in our understanding of genome editing. This technology can be used to make precise changes in sequences of DNA, acting like a pair of molecular scissors that can cut a target gene sequence directed by a customisable protein. It was originally a component of the bacterial immune system that could cut through DNA, and now it has been repurposed as a gene editing tool. CRISPR can be programmed to cut only a specific DNA sequence. CRISPR is made up of two major pieces: CRISPR-associated (Cas) nuclease, which binds and cuts DNA, and a guiding RNA sequence (gRNA), which directs the Cas nuclease to its target. When the target DNA is found, Cas9 — one of the enzymes produced by the CRISPR system — binds to the DNA and cuts it. This process can be divided into five steps.

> **THUS, THERE IS STILL LARGE AMOUNTS OF TIME LEFT FOR US TO TRULY REACH THE LEVEL OF CONTROL REQUIRED OVER GENETIC ENGINEERING TO REACH SUCH HIGH LEVELS.**

A small piece of RNA is designed to match the target DNA sequence that needs to be edited. The gRNA is combined with a Cas9 protein, which acts as molecular scissors. The guide RNA leads the Cas9 protein to the specific location in the DNA where the edit needs to be made. Once the Cas9 protein reaches the target site specified by the gRNA, it cuts the DNA strands. When the DNA is cut, the cell's natural repair mechanisms kick in. There are two main repair mechanisms:

1. Non-Homologous End Joining (NHEJ): This pathway can introduce small insertions or deletions at the cut site, disrupting the gene's function.

2. Homology-Directed Repair (HDR): In this pathway, a DNA template can be provided along with the CRISPR system to introduce specific changes at the cut site.

I hope that you're not confused by the big words! Put simply, CRISPR uses a lot of different proteins and enzymes that help it to locate and cut any pre-specified gene.

However, genetic engineering also comes with its drawbacks. An example of this is Dolly the sheep, the first ever cloned animal from an adult cell. Its birth was a memorable instance for the entire scientific community, as cloning was thought to be impossible before this. However, both Dolly and another cloned sheep, Cedric, passed away from sheep pulmonary adenomatosis (SPA). These deaths are statements to the possible lethality of cloning and how not all genetic engineering can be used to benefit us at this moment. Thus, there is still large amounts of time left for us to truly reach the level of control required over genetic engineering to reach such high levels.

Coming back to the beginning of this article, where I said that we can choose what we want our children to look like. Imagine the real-life applications of this technique. We can engineer humans to have superhuman abilities, to be able to breathe in carbon dioxide and release oxygen to reverse global warming, and we can even create entirely new species of animals that can live on Mars. I leave you with a question today: Do YOU think CRISPR is the key to the future?

NATURE'S ENGINEERS

by Rafay Habibullah

For thousands of years, humans have taken for granted that tool use is a unique property available only to us. However, recently, scientists have discovered that many other organisms also create tools for many reasons, from solving crucial problems to easing their lives. From primates using sticks to capture insects to birds breaking nuts open with stones, many animals display a capacity for tool use. One particularly fascinating and recent example comes from the ocean, where humpback whales create "bubble nets" to trap fish—an intriguing behavior. This shows just how sophisticated marine species can be, broadening our understanding of intelligence in the animal kingdom, and showcasing how we are still learning about the animals around us every day.

Tool use among animals is the ability to manipulate objects to achieve a specific purpose. The first animals that come to mind when tools are mentioned are our closest cousins: primates. They have been widely studied for this, and chimpanzees usually stand out as exceptionally skilled tool users. They use sticks to 'fish' for termites in their termitariums and even use leaves as sponges to collect water for later use. These behaviors express that these apes possess qualities of problem-solving, adaptability, and a deep understanding of consequences— often linked to higher intelligence.

Birds are also impressive in this regard. New Caledonian crows, for example, are well-known for crafting sticks into hooks to extract insects from trees. These crows don't just use tools—they make them, which is rare in the animal kingdom. Furthermore, some bird species take a step further, using bait-like breadcrumbs to lure fish—an extremely complex behavior that shows how birds can manipulate their environment with tools to secure food.

Image Credits: Pinterest.com

> **What makes this behavior so striking is its adaptability.**

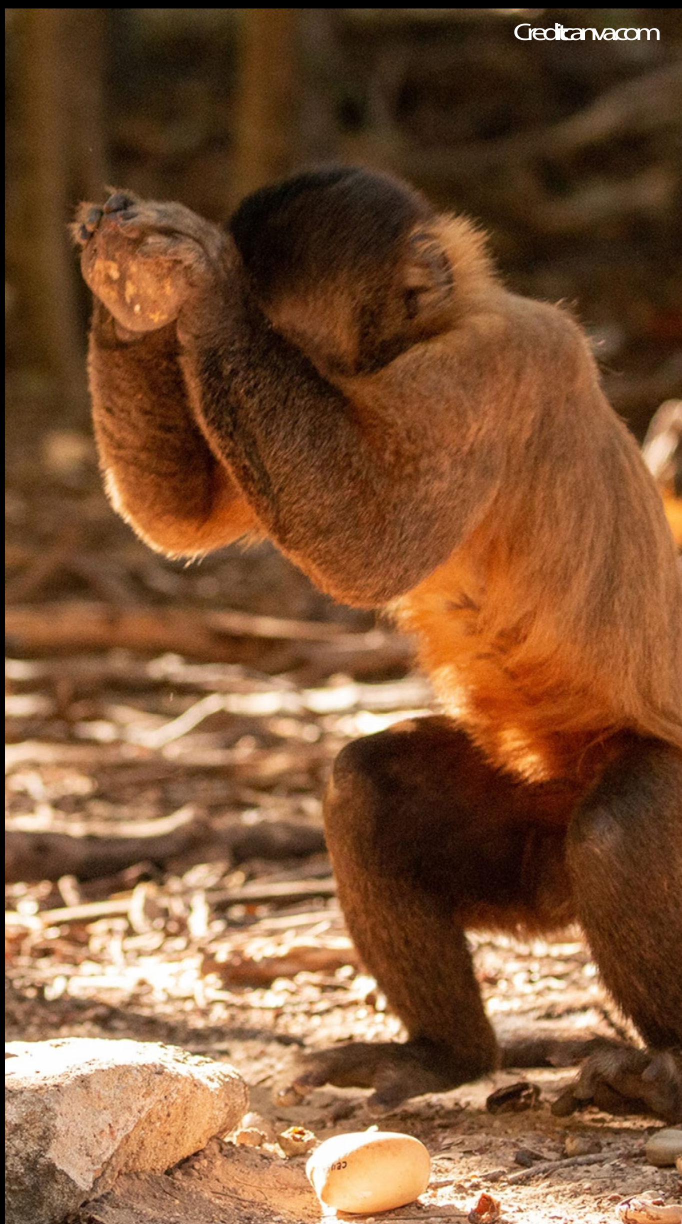
While examples of tool use in the sea are less heard of, they're of no less importance. Sea otters are one of the prime tool users in marine ecosystems, using stones as makeshift anvils to crack open shellfish, an example of their physical skill and strategic thinking. Dolphins use tools like sponges to protect their snouts while foraging on rough seabeds. This allows them to safely hunt in areas where sharp rocks or coral could otherwise cause injuries. However, when talking of tool use in the ocean, one of the most extraordinary and newfound displays of tool use comes from humpback whales. While their elaborate songs and long migrations have long enraptured scientists, discovering their bubble net feeding technique adds a new layer to their behavior. In this complex strategy, a whale swims beneath a school of fish, blowing bubbles in a spiral or circular pattern. These bubbles trap the fish in a tight formation, making them easier to catch as the whales surge upward, mouths wide open, swallowing thousands of fish in one swift move.

What makes this behavior so striking is its adaptability. The whales can adjust the size and shape of their bubble nets depending on the prey they're targeting. When hunting smaller fish, the nets are tighter and more concentrated. For larger prey, the bubbles spread out over a wider area. This ability to fine-tune their hunting strategy suggests environmental awareness and problem-solving that isn't often attributed to marine animals.

The adaptability we see in these animals mirrors the behaviors of many land species. For example, chimpanzees don't use the same stick for every termite hunt; depending on the situation, their tools can vary from foraged sticks to even handmade tools formed from leaves or vines. This shows that these animals foster a deep understanding of their surroundings and an ability to learn from experience—traits shared by many creatures, on land and in the sea.

In the end, this shows us that intelligence is something that animals are capable of having just like us. Organisms across the animal kingdom have evolved more sophisticated strategies to cope with their environment, resolve problems, and increase chances of survival as well. The more we study them, the more we learn about their flexibility and recognize that human exceptionalism is an illusion.

Whether primates using sticks or whales crafting bubble nets, animal ingenuity continues to surprise our greatest thinkers and make ripples in our scientific world, making it clear that we share the planet with beings far more intelligent than we imagine.



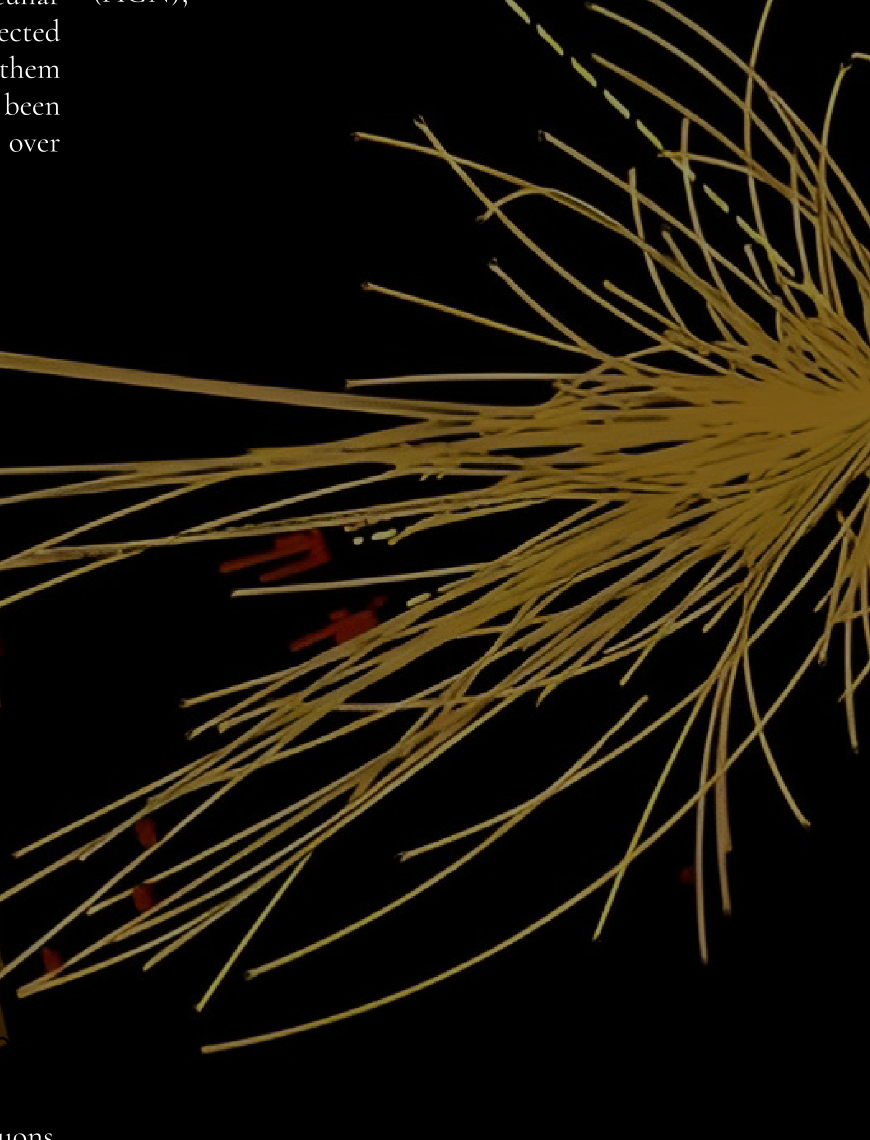
THE GHOST PARTICLE

by Anshuman Gupta

Neutrinos, a concept first visualised by Wolfgang Pauli when he observed an abnormal violation of energy conservation in a beta decay experiment. He proposed the existence of an invisible particle that absorbed the energy. Later on, this theory was further built upon with works from Enrico Fermi who named this particle as "neutrino". But it was not until 1956 that Clyde Cowan and Fredric Reines assured the world of the presence of these newly born particles, through an experiment near a nuclear reactor that greatly widened the scope of atomic physics and thus revolutionised the field of study. Among all the rare particles, neutrinos hold a distinct and peculiar position. These ghostly particles can pass undetected through ordinary matter, which makes detecting them fairly difficult. Conceptualising these particles has been one of the most credited research in Atomic physics over the last decade.

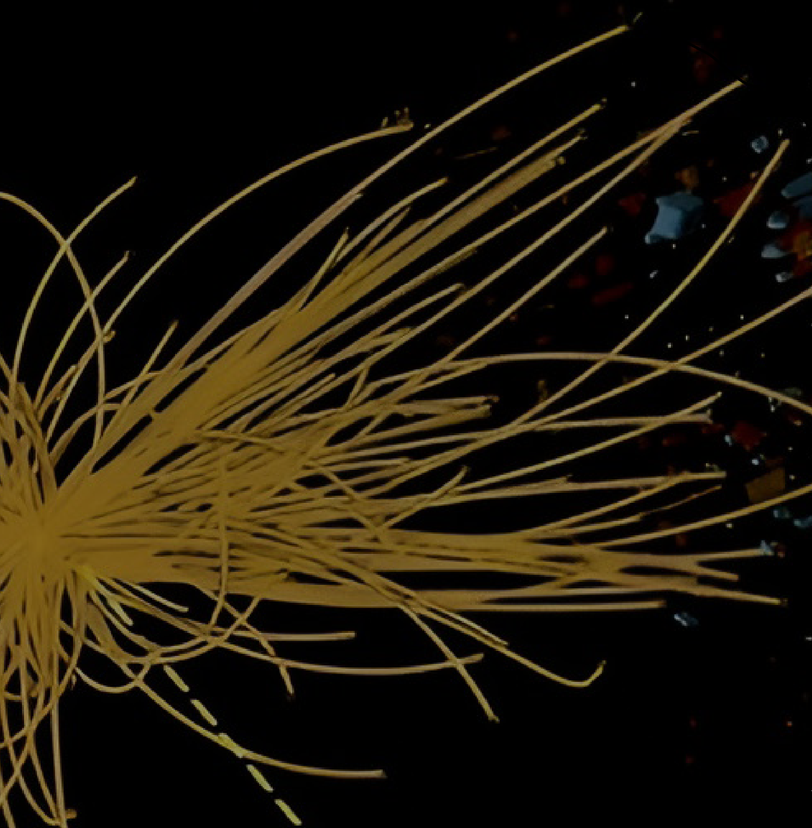
Neutrinos are an elementary particle with a sub-family of atomic particles called leptons and contain other sub-particles such as electrons, muons, and tau particles. They have zero electric charge and their masses are extremely miniscule. Due to this, the only forces acting upon them are very weak gravitational forces, and because of that, they can interact with matter weakly. It is this weak interaction that renders neutrinos so elusive. Every second, trillions of neutrinos pass through our bodies without us noticing. There are three types of neutrinos, electrons, muons, and taus. Neutrinos form in various processes, such as nuclear reactions inside stars, explosions in supernovae, radioactive decay, and via the interaction of cosmic rays with particles in the Earth's atmosphere.

One of the leading theories about the source of high-energy neutrinos involves cosmic rays. Cosmic rays are charged particles (essentially protons) travelling at nearly the speed of light through space. They interact with the interstellar medium, gas and dust, or with radiation fields, and produce secondary particles like pions, both charged and neutral. These subsequently decay into muons and neutrinos. The decay of charged pions results in the muon neutrinos, whereas neutral pion decays will produce the gamma rays. Therefore, accelerating cosmic rays to energies above hundreds of TeV will be accounted for by the same regions that accelerate cosmic rays, including supernovae remnants, active galactic nuclei (AGN),



or gamma-ray bursts. They also serve as natural sources of high-energy neutrinos. Particles in these explosions could reach relativistic speeds and therefore supernovae would be plausible sources of high-energy neutrinos. The shock waves supernovas generate can act as sites for cosmic ray acceleration, and interactions between those high-energy particles and the surrounding material produce neutrinos.

Active galactic nuclei are the most luminous and energetic objects in the universe, comprising a supermassive black hole in the centre of the galaxy. Accretion disks, present around it, are made of gas and dust that shoot off tremendous amounts of radiation while falling into the black hole. Some AGN shoots out relativistic narrow beams of particles travelling close to the speed of light from the black hole's poles. Accordingly, the AGN jets are considered prime candidates for accelerating cosmic rays. The interaction of those cosmic rays with the dense environment around the AGN might produce high-energy



neutrinos. They therefore represent among the most promising sources of high-energy neutrinos.

Gamma-ray bursts are bright flashes of gamma radiation that are of extremely short duration, thought to be produced by the explosion of massive stars in supernovae into black holes or by the collision of neutron stars. GRBs represent the most powerful events in the universe, emitting more energy in a few seconds than the Sun will produce in its lifetime. The relativistic jets in the GRBs can accelerate cosmic rays to ultra-high energies by producing neutrinos as a consequence of such acceleration. Some models indicate that GRBs should be one of the most significant sources of high-energy neutrinos, even though detecting neutrinos from these events is challenging because of their extremely short duration and huge distances.

Detecting neutrinos is difficult, but with the construction of the IceCube Neutrino Observatory at the South Pole this became plausible. IceCube is a huge detector deeply embedded within Antarctic ice, using a grid of sensors to spot flashes of light from neutrinos interacting with ice. With the discovery in 2013, IceCube was able to detect the first-ever high-energy astrophysical neutrinos. These neutrinos had energies far beyond those produced in the Sun or Earth's atmosphere, proving their origin from sources farther away from Earth that are highly energetic cosmic sources. Since then, the detection of high-energy neutrinos by IceCube has continued, complementing efforts towards identifying probable sources, including AGN and GRBs.

High-energy neutrinos form a unique tool to probe the most violent environments hosting the universe. Unlike charged cosmic rays deflected by magnetic fields, neutrinos travel in straight lines, offering a direct line of sight toward their source. Due to their weak interaction with matter, they are capable of escaping from dense astrophysical objects like black holes and neutron stars, carrying information on regions of the universe that otherwise would remain invisible. Identification of neutrino sources will help find out the mechanisms responsible for accelerating the particles to this extraordinary energy. High-energy neutrinos originate in the most violent and energetic processes, from supernovae to AGN and GRBs. Improved detection techniques and continued searching by observatories like IceCube will shed new light on the most enigmatic phenomena of the universe.

In a way, high-energy neutrinos are a unique probe into the most hostile environments of the universe. Being electrically neutral, they aren't deviated by magnetic fields like charged cosmic rays are , and moreover travel in straight lines to the observer, which is direct line-of-sight into the source. Due to their weak interaction with matter, they can escape from the dense astrophysical objects such as black holes and neutron stars carrying information from regions of the universe which otherwise would be invisible. Determination of the sources of neutrinos will help discover the mechanisms that accelerate particles to such fantastic energy. The origin of high-energy neutrinos is from the most violent and energetic processes, starting from supernovae to AGN and GRBs. Nevertheless high-energy neutrinos have opened new frontiers in astrophysics, providing important insight into some of the most violent processes in the universe.

Image Credits: Unsplash.com

Deepfakes are images or videos generated by artificial intelligence and have become so advanced in their realism that sometimes it is very difficult to trace the differences compared to a genuine situation. With synthetic creations becoming more realistic by the day, researchers fight back with creative ways to detect them. One pioneering study analyzing eye reflections using principles derived from astronomical research, presented on July 15 at the Royal Astronomical Society's National Astronomy Meeting in Hull, England, unveiled an outstanding novel technique in this field.

Deepfakes often include small anomalies that can give them away, and reflections in the eyes can be one indicator. In genuine photos, there tends to be a pattern consistent with the environment in the reflections of someone's eyes. If one takes a picture of someone in a room, say, and there are many light sources, that pattern tends to reflect in both eyes. Deepfakes most often display inconsistencies in these kinds of reflections.

In their work, Kevin Pimbblet, an astronomer at the University of Hull, and his former graduate student, Adejumoke Owolabi, exploited a technique that astronomers pioneered in analyzing light distribution in galaxies. In these analyses, researchers employed an index used for measuring light distribution inside astronomical images: the Gini coefficient. This index assesses how reflections are lit up inside each eye in a photograph. When classifying galaxies by light distribution, astronomers use the Gini coefficient—a coefficient of 1 implies that all the light is in one pixel, while 0 implies a uniform distribution in pixels. In reflections of the eye, this measure allows us to quantify discrepancies in the reflections between the left and right eyes.

Pimbblet and Owolabi calculated that the Gini coefficient for eye reflections in deepfake images was usually very asymmetrical between the left and right eye. Real images were typically much more symmetrical. They found that in roughly 70% of staged images, the difference between the Gini coefficients of the left and right eye reflections was significantly larger than those of real images. Pimbblet said that the physics in deepfake images is actually incorrect when examined properly. That the Gini coefficient can find such differences at all serves as a warning flag; it is by no means foolproof. A large Gini coefficient difference indicates that the image is likely to be fake but does not establish that. As Pimbblet puts it, "We can't say that a particular difference in the Gini index corresponds to any kind of fakery, but we can say it's a red flag and that there might be an issue."

This might hold true for videos as well, extending the potential use of this approach in combating deepfakes in motion. But the technique is not a catch-all solution. There could be challenges even with real images: for instance, when a person blinks or is very close to the light source, the latter case could make the reflections seem inconsistent in real photos, too. Given the limitations, however, we must realize that the technique is an important step forward in the war against deepfakes. A new perspective, testing image authenticity with previously unused methodologies from any other scientific discipline. And in the ongoing fight against digital deception, while AI technology grows and improves, so do the methods pursued by researchers.

Other approaches that have also been considered for identifying deepfakes, besides eye reflections, include analyzing facial movements and expressions and detecting inconsistencies in lighting and shadows; the use of machine learning algorithms is also common in identifying anomalies that may indicate manipulation. At the same pace as deepfake technology develops, robust detection methods must be established to preserve the integrity of digital media. In this way, deepfake technology could have significant implications: from misinformation and propaganda to personal privacy violations. With further improved methods of detection, researchers aim to reduce risks associated with such technologies and to enhance our ability to distinguish real content from fabricated images.

Taking cues from astronomical techniques used to analyze eye reflections, scientists have developed this technique that could promise better detection of synthetic images and videos. But, again, this technique is not without its challenges, and all this is part of an integral process toward improved detection of digital deception. This is going to be a cat-and-mouse race in which, with continuously developing technology, ongoing research and development will be necessary to outpace emerging threats in the realm of deepfakes.

DETECTING DEEPFAKES

by Shaaktam

Image Credits: Unsplash.com

mRNA VACCINES

by Arnav Tiwari

During the early stages of the COVID-19 pandemic, no one could have imagined a development and consequent deployment of mRNA vaccines. As of today, mRNA-based vaccines from Pfizer-BioNTech and Moderna constitute the novel control of the COVID-19 virus. While highly lauded for their swiftness and efficacy against the COVID-19 virus, potential mRNA technology stretches way beyond this pandemic caused by COVID-19. Scientists are now researching if the technology of mRNA can be applied to fight many of the toughest diseases on earth, including cancer, HIV, and malaria.

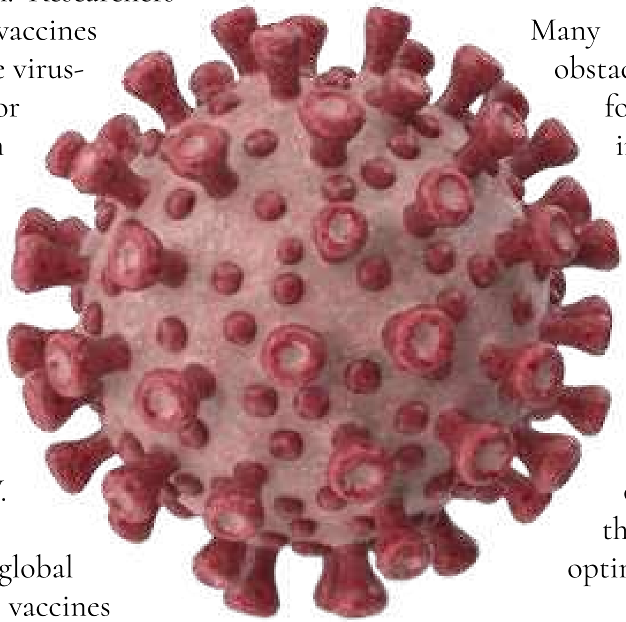
Let's first explore in detail how they work. Messenger RNA, or mRNA, is a genetic material that carries instructions from DNA to the protein-making machinery in our cells. Unlike traditional weakened virus vaccines that have relied upon the insertion of synthetic mRNA in order to instruct cells on how to produce an innocuous protein, mRNA vaccines instruct cells to make the harmless protein. In the case of COVID-19, this is the spike protein found on the surface of the virus. The immune system will learn to recognize and destroy this protein, now preconditioned to fight the real virus later. This versatile approach for vaccine development should be at the heart of its future applications.

Another promising avenue of research is mRNA technology to make tailor-made vaccines for cancer. Since

Image Credits: Vectorpro.com

cancer arises from the very cells of the human body, the immune system does not know how to target them for action by the latter. Scientists are conducting research on mRNA-based vaccines that focus on proteins specific to a patient's tumor. Through mRNA injection that codes for those proteins, the immune system can be primed to kill cancer cells. So far, studies in melanoma patients have shown early promise and are already being ventured into by companies, such as BioNTech.

This is another challenging one: HIV. Being a fast-reproducing virus, offering multiple strains, makes it very hard to beat with conventional vaccine technology. mRNA-based vaccines are more feasible because they can be designed to any strain. Researchers have also attempted to develop vaccines targeting the stable parts of the virus-the outer envelope protein, for instance-and Moderna began human trials in 2022 of an mRNA-based HIV vaccine. Of course, it is too soon to say for certain, but there at least exists the promise that, unlike all previous forays, mRNA technology might finally yield the long-sought kind of vaccine for HIV.



Malaria is just one of the many global health issues that mRNA vaccines might be able to resolve. The life cycle of the malaria parasite, which includes several stages, has always posed a problem to scientists while attempting to develop the traditional vaccine. Things look a bit brighter with mRNA because of its flexibility in design. Researchers are working on multi-stage mRNA vaccines which can instruct the immune system to take a chance and hit the parasite at different stages thus mostly improving the chances of disease prevention. BioNTech already has a malaria vaccine under development, and is now at the stage of planning clinical trials. The potential impact is millions of lives saved.

What's revolutionary about mRNA technology is its flexibility and speed: Given that the target protein might turn out to be a viral one, a cancerous one, or from a parasite, researchers can very rapidly design the corresponding mRNA. This adaptability to rapidly shift in terms of evolving pathogens such as those that cause HIV or influenza gives mRNA vaccines the competitive edge needed to address a vast area of diseases. Probably their greatest promise is in the realm of personalised medicine, especially within the cancer treatment landscape.

While adaptability has proven to be an important feature of the mRNA vaccine technology, it also allows for the production of vaccines at a much faster and less expensive pace than traditional vaccines. Importantly for public health all over the world, the mRNA vaccines were rapidly scaled up to meet the global demand during the COVID-19 pandemic. This scalability and adaptability might prove to be the cornerstone of future health crises. Developers and distributors of this technology toward other diseases may help to change the business model of the development and distribution of vaccines globally.

Many benefits notwithstanding, obstacles have to be surmounted: for instance mRNA instability-in that it must be kept at extremely low temperatures. As one can see, this is much more of a challenge in lower-resource parts of the world. mRNA vaccines are still in the process of optimization towards producing long-lived immunity for diseases outside of COVID-19. Perhaps there will be yet another optimal answer to each disease.

The COVID-19 mRNA vaccines have opened a new era in medical science, and though more challenges are ahead, the vast scope of applications of mRNA technology can be perceived through combating diseases like cancer, HIV, malaria, and other diseases yet to be identified. Once research advances, mRNA technology can alter the course of medicine, subsequently addressing many of the world's most complex health issues. The future of mRNA is likely to be found in its potential use in helping to provide speedy, patient specific treatments and to help address emergent global health threats.

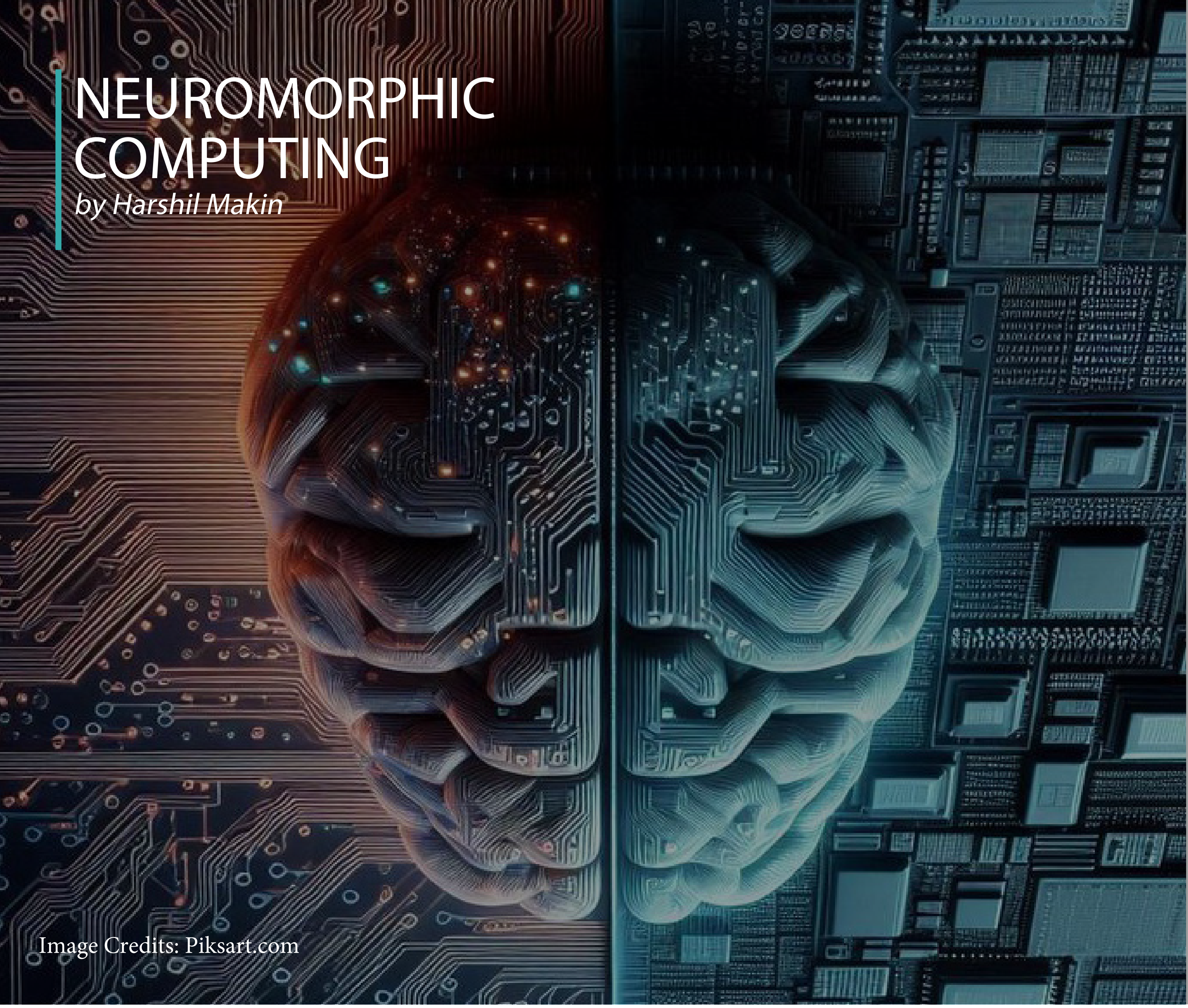


Image Credits: Piksart.com

Imagine a world where computers not only process numbers but also think and learn like the human brain. This may sound like something from a science fiction show, but it's closer to reality now, thanks to neuromorphic computing. This developing field of technology aspires to mimic the way our brains work, letting machines process information in a more energy-efficient, adaptive, and even brain-like manner. So what exactly is neuromorphic computing, and why is it a game-changer?

Unlike traditional binary computing, which processes data as a series of 1s and 0s, the brain operates through complex networks of neurons and synapses. Instead, we see networks of neurons and synapses—connections that transmit all the various sorts of information that we humans use in our day-to-day lives. The human brain functions more like an analog system, processing information in ways that differ from both digital and electronic systems. It is done in a way that is certainly not digital and is also not quite up to the standard of true "smart electronic" systems either. The brain's networks accomplish what really seems to be an impossible task with such "cheap" (i.e., low power) circuitry that can somehow make use of the sorts of high voltage and current found in the biological world.

A good way to grasp the contrast between neuromorphic computing and traditional computing is to compare the operation of the human brain with that of a standard computer. The human brain is stuffed with billions of neurons that work in concert to handle endless amounts of information, enabling lightning-fast decisions, face recognition, and problem-solving. When you see a dog, for example, billions of neurons are busy processing all the visual details that make the dog a dog, from its shape and size to its colour and texture.

Conversely, traditional computers process information in a linear, step-by-step way. They are remarkably swift when it comes to performing calculations, but they hit a wall when the work requires learning, adaptability, or even just pattern recognition—areas where the human brain excels. So, a computer can crunch numbers in a heartbeat, yet might take aeons (by computational standards) when asked to solve an equivalently complex object-recognition problem.

The aim of neuromorphic systems is to narrow the gap between specialised hardware and the brain's information processing. The spiking neural network (SNN) is one of the key technologies in neuromorphic computing. It mimics how neurons in the brain communicate with one another, or not, through short electrical bursts or spikes. Heaven forbid the SNN be the only key to interpreting large amounts of data, like speech and image recognition; however, it is an efficient set of spikes for any task using that kind of voice or visual deciphering.

Neuromorphic computing's most thrilling element is the creation of customised chips that duplicate the essential role of neurons and synapses in the brain. The primary representatives of this nascent technology are IBM's TrueNorth and Intel's Loihi, which boast millions of microscopic "neurons" and "synapses," types of artificial brain cells. When compared to traditional computing architectures and their straightforward numeric operations, neuromorphic chips offer an entirely different approach—one that could potentially yield a clear path toward achieving real-time, brain-like learning and functioning in machines.

Neuromorphic computing has an almost infinite number of possible uses. One is in the field of artificial intelligence, where neuromorphic systems could help "machines learn and adapt 'in the wild', that is, learn and adapt during real-time interactions with humans." This is something current AI systems can not do, instead they require massive amounts of data and repetitive processes to "learn" how to serve their human operators and, frankly, distinguish themselves from the pre-neuromorphic computing era.

Robots could naturally interact with their environments if they were equipped with neuromorphic computing. For instance, a robot using a neuromorphic chip could navigate a complex space, make the kind of quick decisions a human might make, and learn from observing what a human does in the same situation. This scenario is especially useful in considering industries like healthcare where a robot may assist in delicate tasks or interact with patients.

Reforming healthcare and neurology might happen through the enormous potential of neuromorphic computing, too. Thought-controlled interfaces could become a lot more efficient and way more responsive if we make them using the kinds of circuits that brains use. Meanwhile, we're bound to discover new ways to interpret and respond to signals from the brains of types of people with certain neurological disorders, like Parkinson's or epilepsy. Treatments for memory problems, like Alzheimer's, might get some help from our still-imperfect understanding of how to mimic the brain and interpret its signals.

While there are many upsides to neuromorphic computing, some difficulties remain to be tackled. Foremost among these is making hardware that can accurately replicate the brain's complexity. The human brain contains nearly 86 billion neurons, while the most advanced neuromorphic chips today can barely simulate a small fraction of that. Another big question is ensuring that these systems are reliable enough and scalable to sufficiently power their many potential real-world applications—from smart consumer devices to data centres—when compared with their current electronic rivals. And what about the ethics of neuromorphic computing? If machines can mimic human cognition, what will that mean for jobs, privacy, or the very nature of human intelligence?

The future of neuromorphic computing is very bright indeed. As research moves forward, it is not inconceivable to think that we might see constructed entities that can perform basic brain-like functions. Such machines might be capable of a kind of thinking, learning, and adapting that happens from moment to moment in our lives and was previously thought to be purely the province of the human brain. They certainly will be capable of doing this sort of function at a speed and energy level beyond what our current computers can manage. And it's still too early to tell just how revolutionary such systems might be in regard to fields like AI, robotics, and even healthcare.

The field of neuromorphic computing has the potential to take us far closer to our goal of developing thinking machines. Systems like these that are based on mimicking the structure and function of the brain could—if data from the field continues to turn into usable advances, as seems likely—lead us toward the development of technology with profoundly different capabilities. Ultimately, neuromorphic systems could give rise to smarter, more adaptive machines capable of revolutionising how we interact with technology.

DARK ELECTRONS

by Shrikritt Jajoo

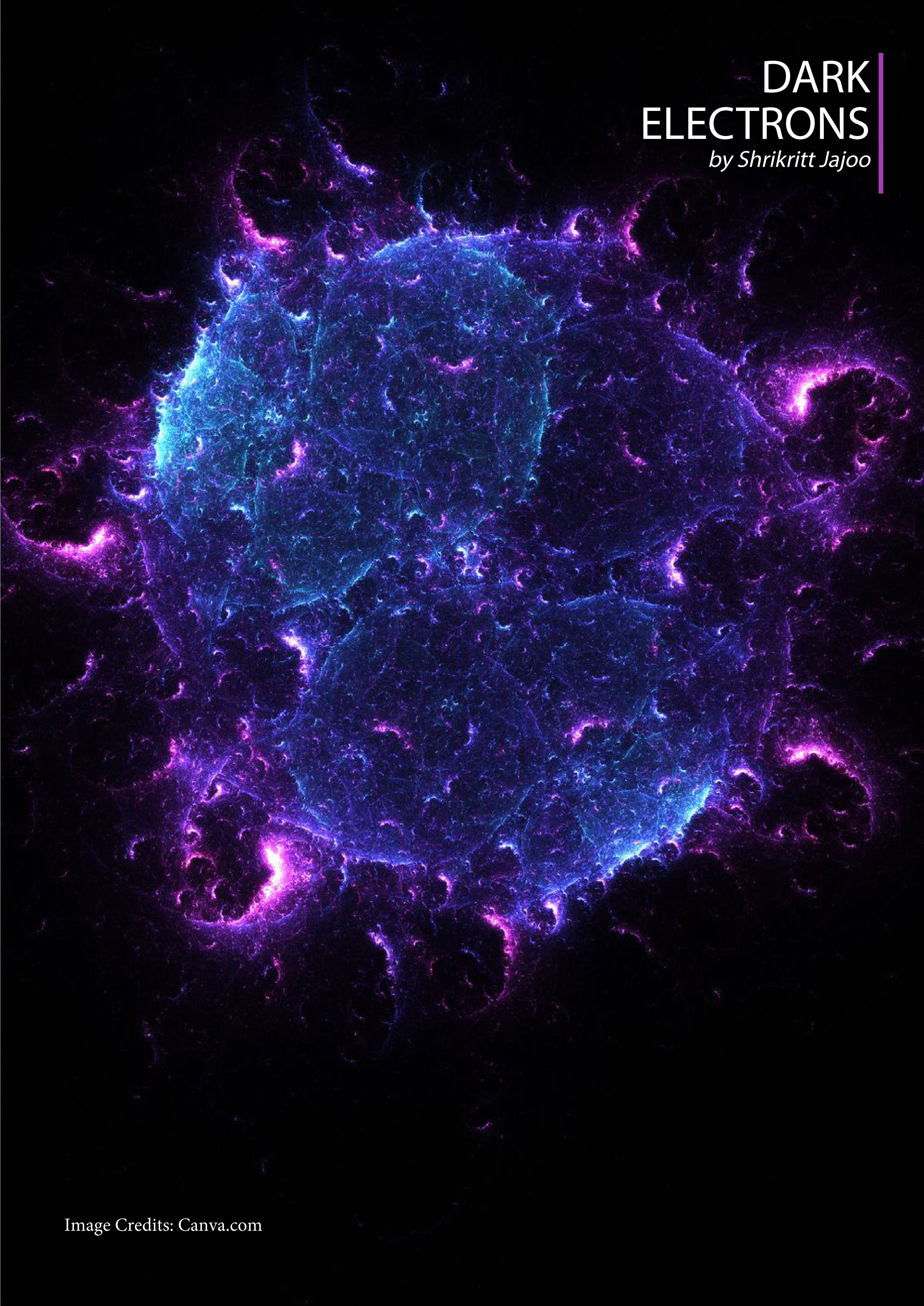


Image Credits: Canva.com

The discovery of dark electrons in solid matter is an enormous breakthrough in quantum physics, displaying complex electronic behaviour that was previously unobserved. These electrons exist in a dark state where they are invisible to all electromagnetic radiation, making them undetectable through conventional sensing methods. Although replication of these findings is pending, this experiment does highlight the accelerated speed of scientific evolution in the age of data.

Although the term "dark electrons" might depict mysterious invisible particles, they are simply electrons that exhibit unusual quantum properties due to their environment. This is due to the material being composed of two interwoven lattices of atoms, where the arrangement and interaction between the atoms cause the electrons to behave differently from what we normally observe. It's like two overlapping grids, each with its own pattern; the electrons must adapt to both, resulting in unusual behavior that makes it sort of invisible.

Electrons in conventional materials either freely move through the lattice (as in metals) or are constrained (as in insulators). But dark electrons, in contrast, seem to "hide" in these sublattices, interacting in ways that prevent them from being easily detected using traditional experimental techniques. However they still participate in the material's electrical and magnetic behaviour, but in a way that's currently undetectable — thus the name "dark" electrons.

Scientists are able to detect regular electrons using various spectroscopy techniques because they can absorb a photon's energy, allowing atoms and molecules to absorb light. Dark electrons, on the other side, might be fundamental particles that form dark matter. Theoretically they don't interact with any electromagnetic forces, and therefore scientists can't detect their presence using spectroscopy methods. This especially highlights the limitation of science developed by humans there are some things just impossible for us to conceptualise as their existence is inconsistent with out beliefs.

Many previous studies that aimed to find dark electrons used materials such as graphenes that had only one pair of sublattices, a specific repeating arrangement of a subset of atoms within the larger crystal structure of a material. However, in the recent study the researchers chose materials with two pairs of sublattices for their study. This is because they could deduce the number of total electrons (including both regular and dark) in the sublattices of such materials. While conducting the study they had expected to find 4 different types of electron quantum states, however they only found 1, implying the other 3 were invisible states, eeriely similar to dark matter.

This phenomenon could be explained by quantum interference in the sublattice structures; in these materials, the interference between the electron waves effectively cancels them out, rendering the electrons "invisible." This state was experimentally observed using synchrotron radiation facilities, where scientists noticed this destructive interference in cuprate materials, commonly studied for their superconductive properties. What is superconductivity? Superconductivity is a phenomenon during which a material can conduct electricity without any resistance when cooled to very low temperatures. This happens because the electrons in the material form pairs, known as Cooper pairs, that can move through the lattice without scattering, meaning no energy is lost to heat.

Currently, most superconductors only work at extremely low temperatures, close to absolute zero. Because dark electrons interact differently with the material's atomic lattice, they could form new kinds of Cooper pairs or other quantum states that support superconductivity. This would enable dark electrons to form the basis for creating superconductors that have higher operating temperatures. Moreover this could lead to the superconductors which would be more practical and easier to use in everyday applications.

The discovery of dark electrons in solid materials has definitely provided hope to our search of understanding of quantum phenomenon in matter. Furthermore, their potential role in high-temperature superconductivity represents a practical incentive for continued research in quantum materials. As research continues, dark electrons may not only deepen our grasp of quantum physics but also shed light on the tenebrous nature of dark matter.

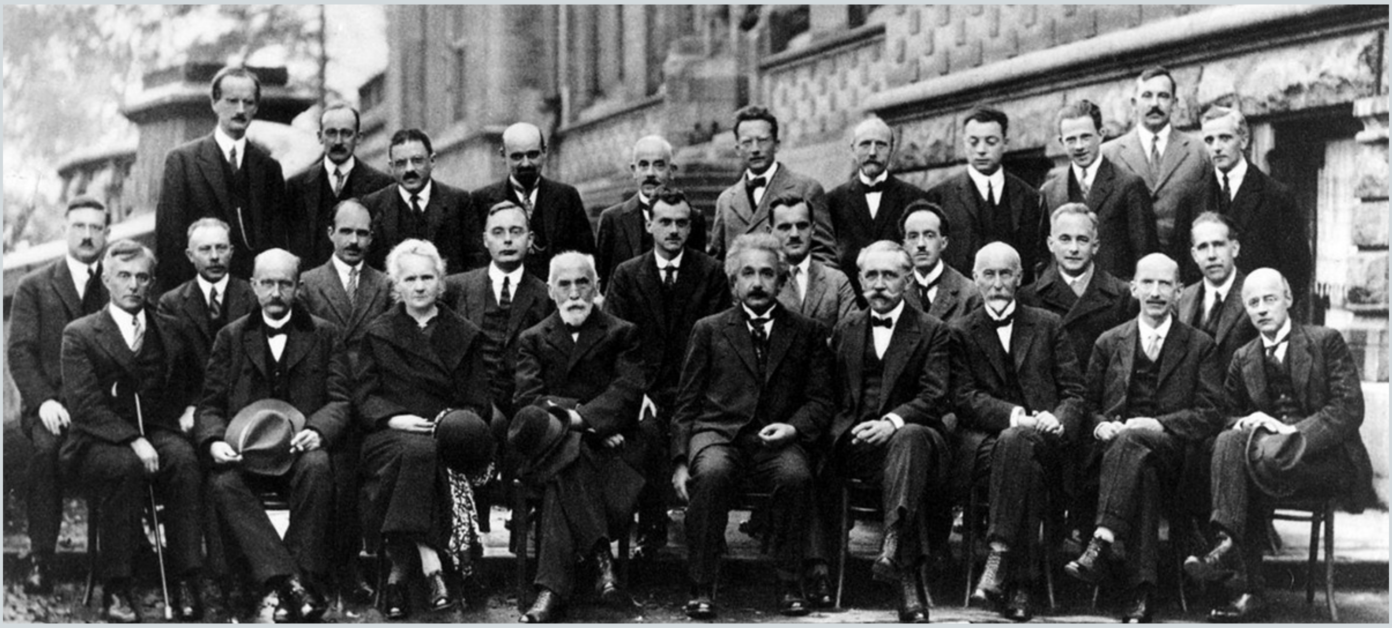


Image Credits: Unsplash.com

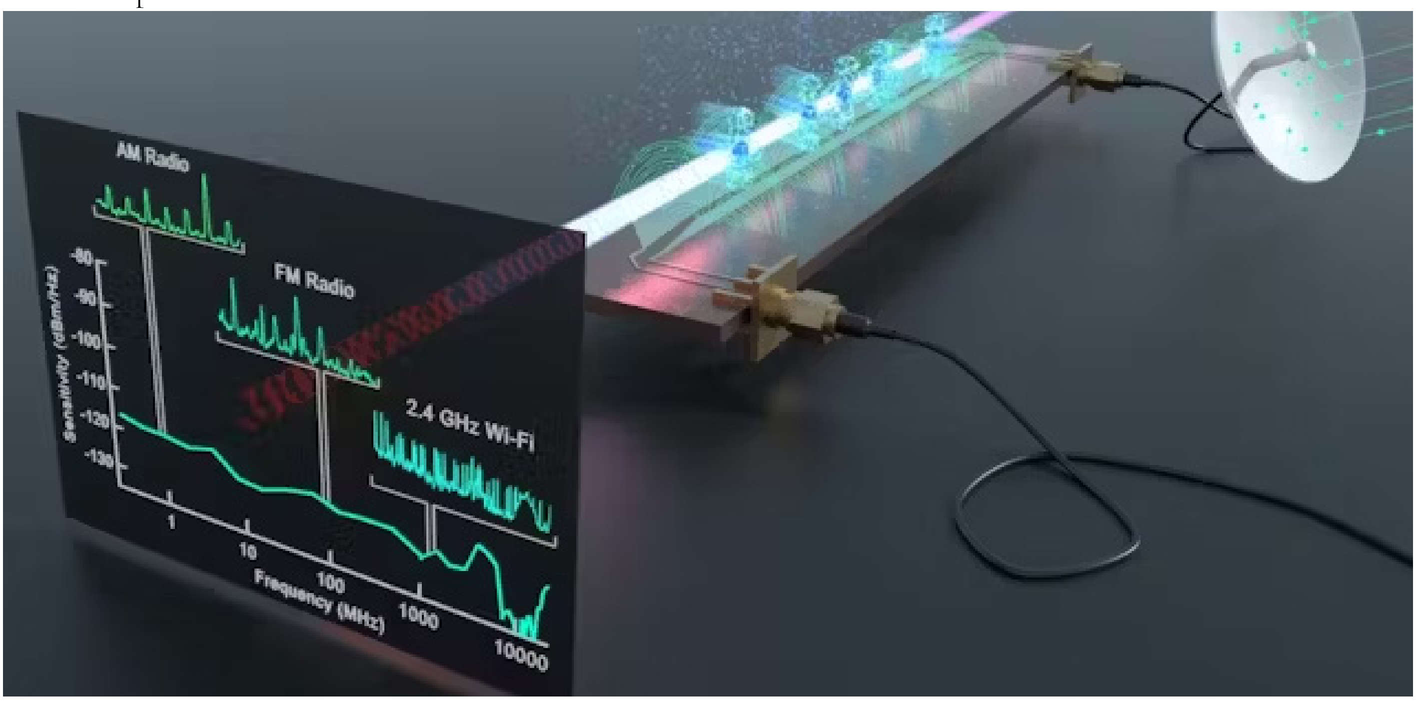
RYDBERG SENSORS

Vir Singh Sandhu

Imagine your phone with an inbuilt Rydberg sensor. It sounds boring, right? But what if I told you that you are in the middle of nowhere with no data, and these sensors can then detect super-weak radio frequencies? That would allow phone towers and satellites to talk to each other with a much better quality, meaning the number of dropped calls would decrease, with an overall better signal in areas that are hard to reach. In simpler terms, imagine how your phone picks up a signal from Wi-Fi or tunes into a radio station. Rydberg sensors can do this even if those signals are weak, finding the tiniest Wi-Fi wave in an extremely crowded room. This therefore enhances wireless communication to allow us faster and much clearer internet.

Rydberg sensors offer an opportunity to change the way doctors treat their patients. Imagine if you went in for a routine check-up at your doctor's office. Would you appreciate lying down inside a big, loud machine like an MRI instead of allowing doctors to use non-invasive, small, easy-to-read sensors to determine your brain waves, heart rate, or other vital signs your body? Rydberg sensors can detect extremely faint electrical signals without the heavy equipment or invasive procedures associated with current monitoring techniques. It enables the measurement of activity in the brains of sleeping patients in real-time, for example, using Rydberg sensors, which allows doctors to monitor and diagnose patients against illnesses relating to epilepsy or sleep disorders without the traditional uncomfortable and inappropriate monitoring. Because of this, patients would not feel uncomfortable due to bulky apparatus or large machines and let the device scan their heads. This would allow patients to provide doctors with more accurate assessments, records, and vitals.

In addition to the disadvantages and discomfort with medical treatment and measurement, regarding navigation, Rydberg sensors are on the verge of making GPS make sense! Have you ever been in a large urban area where you recently used Google Maps and noticed that the signal went "wrong," showing you not where you were located? Or it could get lost, and you would be standing there, wondering where to go. GPS signals based on the ground and atmospheric conditions can degrade and cause difficulties. Rydberg sensors are so sensitive they would be able to detect even the faintest signal possible. We are used to manoeuvring through obstacles—say, buildings, urban environments in general—and typically at



times with little to no infrastructure. The scope for Rydber Sensors is incredible and could transform fields such as healthcare, telecommunications, and quantum technology. In medicine, they could unlock non-invasive, real-time health monitoring such as brain activity, heart activity, and other biometrics. This would allow us to create consumer-health devices to detect early warning signs for conditions such as heart attacks and seizures. In telecom, Rydberg sensors could turbocharge 5G and future 6G networks, drastically decreasing the time it takes to transfer data. Rydberg sensors will enable the next generation of quantum technology and help us develop more reliable quantum computers for solving novel and challenging problems in key areas of artificial intelligence, cryptography, and drug development. They would also help with environmental monitoring, assessing natural fluctuations and conditions with higher degrees and frequencies than current instruments. Similarly, they could assist with deep space missions: tracking details of natural events with various advanced features.

The company Rydberg Technologies recently announced the development of the first long-range radio device in the world based on a Rydberg quantum sensor. The recently demonstrated device at the U.S. Army's 2023 Network Modernization Experiment had high sensitivity across the high-frequency to super high-frequency bands. It will boast high signal selectivity, low probability of detection, and immunity to electromagnetic interference—key features that make this device one of the most advanced in communications technology, particularly for military and intelligence operations. To conclude, Rydberg sensors have a transformative potential for advanced technologies in medicine, telecommunications, quantum computing, and environmental science. Their exceptional sensitivity to electromagnetic signals enables non-invasive medical diagnostics, enhanced communications networks that are faster, safer, and more reliable, and innovations in quantum science. The continued development of such sensors will pave the way to even more prominent innovation, making our technology smarter and more accurate while creating new avenues for future technology.

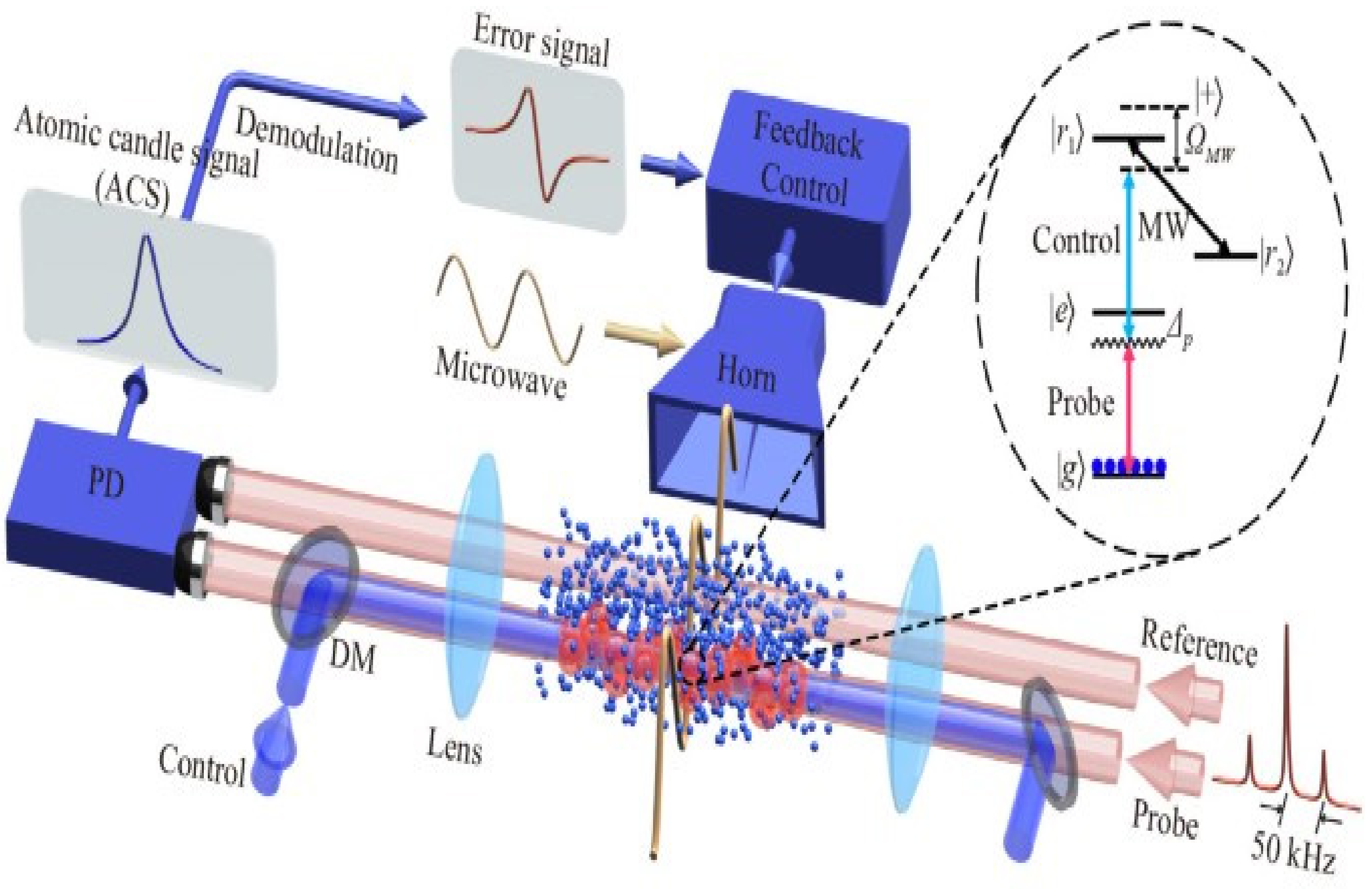


Image Credits: Nature Journal

Ads/CFT

by Tanay Chowdhary

Anti-de Sitter/Conformal Field Theory correspondence, or AdS/CFT, is one of the most significant concepts in contemporary physics. Physicist Juan Maldacena first proposed it in 1997, and it enables us to investigate some of the greatest mysteries in reality, such as black holes, quantum gravity, and particle interaction.

Everything is drawn towards one another by gravity, which is why the Earth pulls us down towards its centre. The science that explains the behaviour of small objects, such as particles, is called quantum mechanics. The issue is that there are certain inconsistencies between these two theories—quantum mechanics and gravity. The hard-to-understand theory of quantum gravity describes how gravity functions on the majority of Lilliputian (small) scales. AdS/CFT helps physicists find solutions to problems pertaining to quantum gravity. AdS is short for Anti-de Sitter, space with negative curvature. Imagine a hill and sending a ball rolling down from its peak. It will move downhill because the surface is curved. With negative curvature, space curves like a saddle. The middle pushes downwards, and the sides curve upwards. The further you go from the centre of this hill, the further everything spreads out. Anti-de-sitter space is where the distances grow larger the farther you move away from something, and it has a weird geometry compared with the space we are used to. On the other side of the AdS/CFT correspondence is Conformal Field Theory, or CFT for short. A field theory generally explains how particles and forces spread out and interact in space. The peculiarity of a conformal field theory is that it does not change, whether you zoom in or out. This means CFT describes systems that look the same on every scale.

The most bizarre thing about AdS/CFT is that these two theories in the higher-dimensional Anti-de Sitter space and the more trivial quantum field theory in the lower-dimensional space have two ways to describe the same thing. One of these theories has gravity, whereas the other does not, yet they are deeply connected. It helps physicists study difficult things, such as black holes and quantum gravity, using simpler tools. Another important notion in the correspondence AdS/CFT concerns the issue of dimensions. In everyday reality, we realise three, length, width, and height. However, in physics, there can be more than this count that we cannot perceive. For example, the dimensionality of AdS space is higher than what we normally experience, while for CFT, it is lower. The thing about this is that even if they appear so vastly different, the physics taking place in a higher-dimensional AdS space can be replicated by what is going on in a lower-dimensional CFT. This connection between AdS and CFT is practical, especially concerning an understanding of quantum gravity. Gravity operates on the tiniest dimensions, such as inside black holes. Rather than try to solve the problem of quantum gravity directly, researchers can use much easier-to-handle tools from CFT. This method has opened the way for some of the greatest discoveries in physics. The most exciting applications of AdS/CFT are related to wormholes and the Einstein-Rosen bridge. Wormholes are, hypothetically, tunnels through spacetime that connect two widely separated regions of the universe, like shortcuts through space and time. The Einstein-Rosen bridge refers to a type of wormhole proposed by Albert Einstein and Nathan Rosen in 1935, and it

is a theoretical connection between two black holes.

More recently, physicists have found that AdS/CFT has something to say about the physics of wormholes. In at least a few idealised situations, the AdS/CFT correspondence seems to insinuate that a wormhole in AdS space might be encoded in two interacting quantum systems that are “entangled”. Entanglement is a strange quantum phenomenon wherein two objects, even when separated by large distances, can become correlated in such a way that the state of one is directly related to the state of the other. The entanglement of two quantum systems in the CFT on the boundary of this type can represent a wormhole, or Einstein-Rosen bridge, in AdS space. In that case, wormholes are a consequence of quantum entanglement. This theory is that it provided the possibility of a traversable wormhole. While this is very speculative, the power of AdS/CFT provides scientists with a deep way to look at tapping such a shortcut through space and time.

The AdS/CFT correspondence proved indispensable in trying to make some pretty serious interpretations of quantum gravity, black holes, and even strongly interacting particles. This opened up wormholes and the Einstein-Rosen bridge- probably linked to quantum entanglement channels of thought. The AdS/CFT correspondence helps connect gravity and quantum mechanics in completely unexpected ways, enabling physicists to at least take a stab at some of the biggest universe mysteries.

Image Credits: Quanta Magazine

ATOMIC PROPULSION

by Rudra Sarin

December 17, 1903 the Wright Brothers flew the first mastered, controlled powered flight in an aircraft, the " Wright Flyer " , inaugurating the aerial age. The initial vessels of the air were rigid dirigible balloons pioneered by Ferdinand von Zeppelin, who opened his business in 1900 and soon dominated the market throughout World War I until faced with competition from large flying boats that became common during the late 1930s.

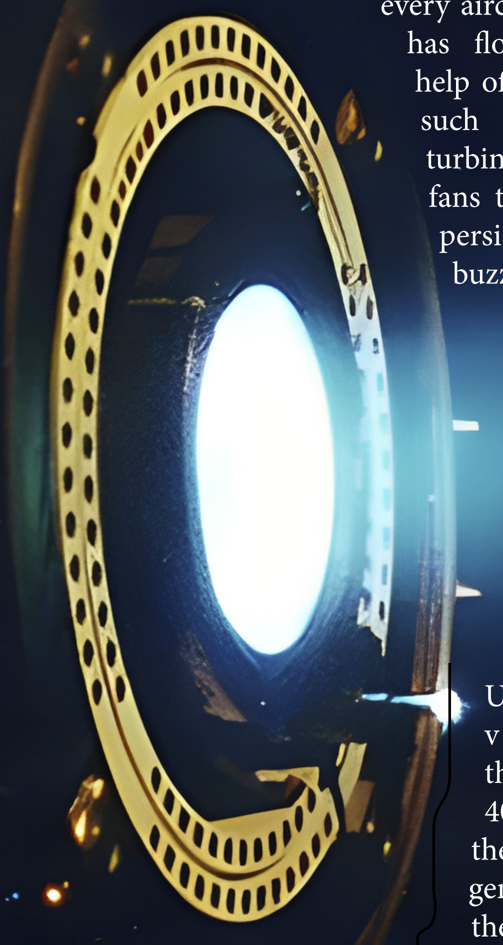
Aircrafts allowed armies to gather intelligence from the skies, providing a tactical advantage. Initially commercial aviation included airlines such as Pan Am and Imperial Airways establishing a new mode of transportation although air travel remained a luxury for the wealthy.The outbreak of World War II once again revolutionised aviation. Such aircrafts played an important role in the conflict, with bombers, fighters, and transport planes being critical to military operations. Jet-powered planes like the German Messerschmitt Me 262, the world's first operational jet fighter, were faster and more powerful than any propeller-driven aircraft. With surplus military aircraft available and improvements in technology, the focus shifted toward commercial aviation. The introduction of jet airliners, starting with the Boeing 707 in the late 1950s, revolutionised air travel by dramatically reducing flight times and making long-distance travel more accessible and affordable. The development of wide-body aircraft like the Boeing 747, which became known as the "Jumbo Jet" took place which were capable of carrying hundreds of passengers, the 747 helped democratise air travel, allowing millions to fly across the globe. The advent of supersonic flight with the Concorde in 1976 enabled the human race to fly across races faster than ever, at the speed of sound!

In the latter part of the 20th century. The advent of digital electronics produced great advances in flight instrumentation and "fly-by-wire" systems.

The 21st century saw the large-scale use of pilotless drones for military, civilian and leisure use. With digital controls, inherently unstable aircraft such as flying wings became possible.

As technology revolutionised along with time new features were introduced which were compiled from several interesting concepts of which the " Ionic Thrust Engine " is one.

Since the first aircraft took flight over 100 years ago, virtually every aircraft in the sky has flown with the help of moving parts such as propellers, turbine blades, or fans that produce a persistent, whining buzz or noise.



Using very high voltages—in the plane's case, 40,000 volts—the thruster generates ions in the air around two electrodes. The electric field created between these throws the ions from a smaller electrode over to a larger one. These ions collide with normal air molecules while travelling, creating the ionic wind and pushing the plane forward. Since the ions are moving between two stationary electrodes, no moving parts are required to power the plane.This phenomenon is known as electrohydrodynamic thrust — or, more colloquially, "ionic wind" — was first identified in the 1960s. In 2018 researchers at MIT ran their own experiments and found that ionic thrusters may be a far more efficient so urce of pr opulsion th an conventional jet engines.

In their experiments, they found that ionic wind produces 110 newtons of thrust per kilowatt, compared with a jet engine's 2 newtons per kilowatt. The special aircrafts weighs 2.4 kg and covers 60 metres while using electricity directly. If the technology could be scaled up (only if), it would significantly contribute to the golden history of aviation etching its name in its pages. Future aircrafts utilising this technology would be safer, quieter, and easier to maintain. Most importantly, it would eliminate combustion emissions, since the process is powered entirely by battery.

When it was conceived of in the 1960s, researchers came to the conclusion that it couldn't create the level of thrust needed to sustain flight. Even if this type of propulsion can't get efficient enough for commercial aircraft, it is believed that it could be used in conjunction with jet engines.

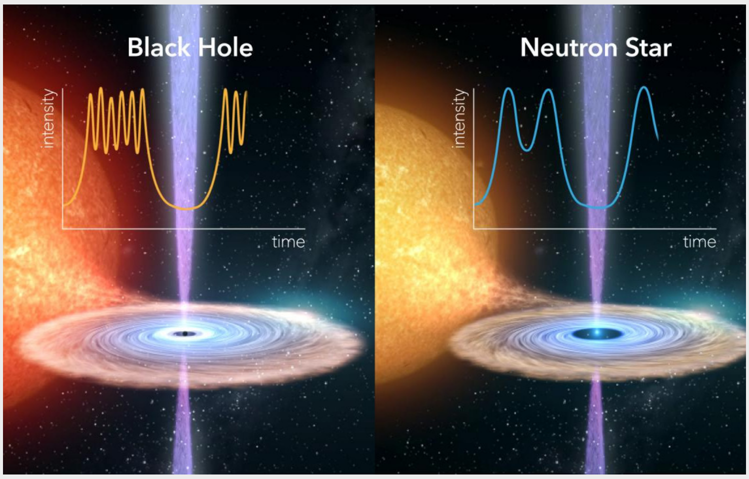
He says that electrohydrodynamic propulsion systems can be embedded in the skin of a plane and used to reenergize the air travelling along the aircraft. As of now in commercial and military aircrafts, this air ends up behind the aircraft, moving slowly and dragging it back. The addition of the new propulsion systems could eliminate this drag and increase fuel efficiency.

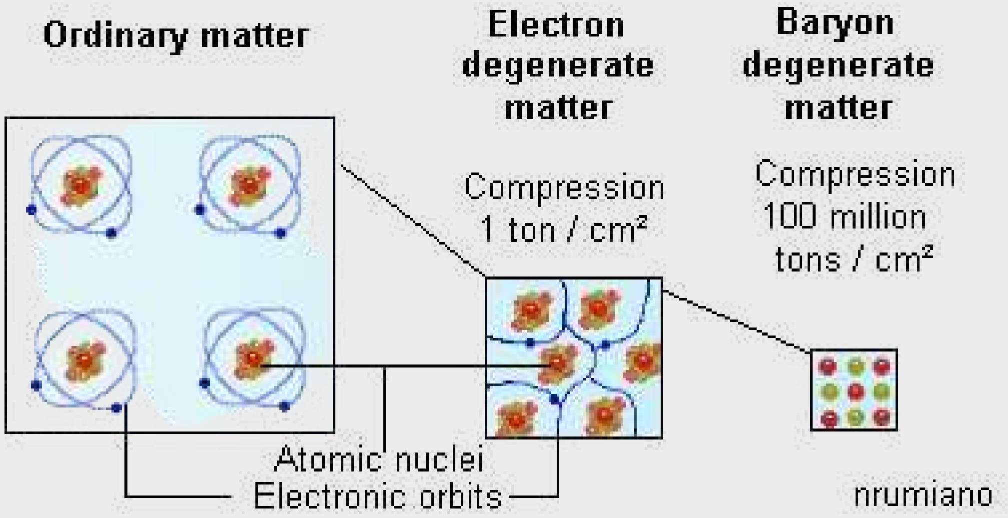
Image Credits: Unsplash.com

EDGE OF SCIENCE
MOST PUZZLING DISCOVERIES IN SCIENCE

Neutron Deengerate Matter

Neutron degenerate matter is an incredibly dense exotic state of matter formed under extreme conditions; during supernovae atoms are squeezed so tightly, mainly due to gravity and the explosive pressure, that their electrons merge into the nucleus, causing protons and electrons to combine into neutrons. This process leaves behind a white dwarf composed almost entirely of neutrons. In normal matter, atoms are filled with a lot of empty space, and electrons orbit the nucleus from a considerable distance. In neutron stars, however, gravity compresses matter so severely that atoms collapse, and the empty space is eliminated; when all lower states are filled and pressure continues to rise, electrons reach a point where they can no longer exist independently without violating the Pauli Exclusion Principle, which states that any two particles cannot have the same quantum state. As a result, they combine with protons to form neutrons, creating a densely packed "sea" of neutrons.

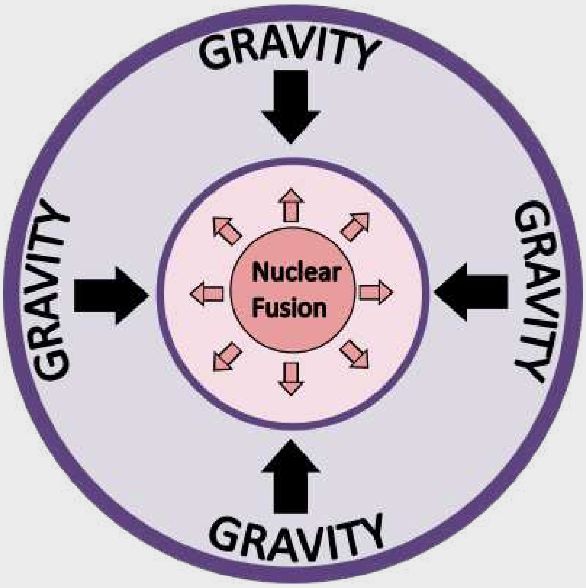


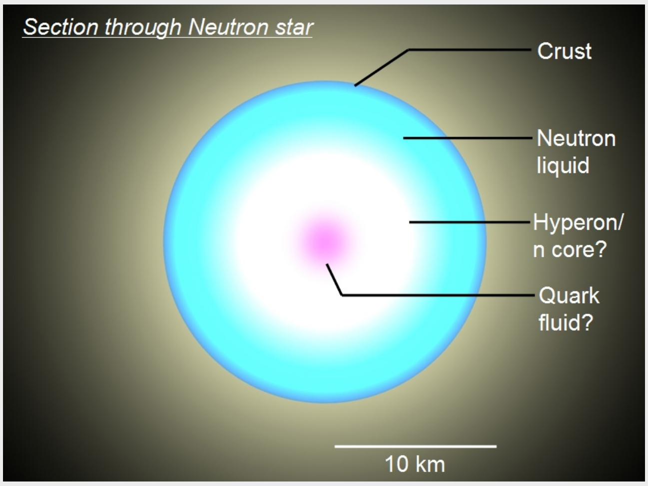


Fun Fact!

Did you know that a single sugar-cube-sized piece of neutron degenerate matter would weigh about 4 billion tons on Earth? This mind-boggling density is possible because neutrons in this matter are packed so tightly, defying normal atomic structure, and are held together by the Pauli Exclusion Principle, which prevents them from collapsing further under immense gravitational pressure in neutron stars.

Another feature of neutron degenerate matter is “degeneracy pressure”. It is a quantum mechanical effect that prevents further collapse by exerting an outward force. Compared to thermal pressure, which depends on temperature, this phenomenon arises purely from the principles of quantum mechanics and the pauli exclusion principle, providing the an enormous amount of force capable of balancing the intense gravitational pull of trillions of kilograms of exotic matter.



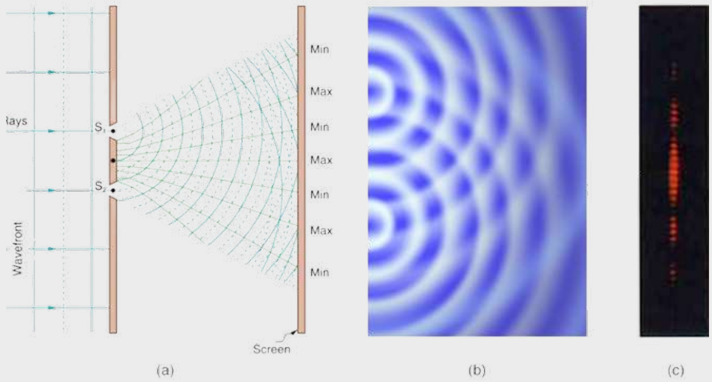


The exotic neutron degenerate matter formed through this process is only theoretical and remains untested, however there is a lot of proof supporting it. Furthermore, due to its extreme density, a single teaspoon of neutron star material would weigh billions of tons on Earth. This density creates massive gravitational and extremely powerful magnetic fields, making neutron stars some of the most mystyfing objects in the universe.

Journey through the History of Light

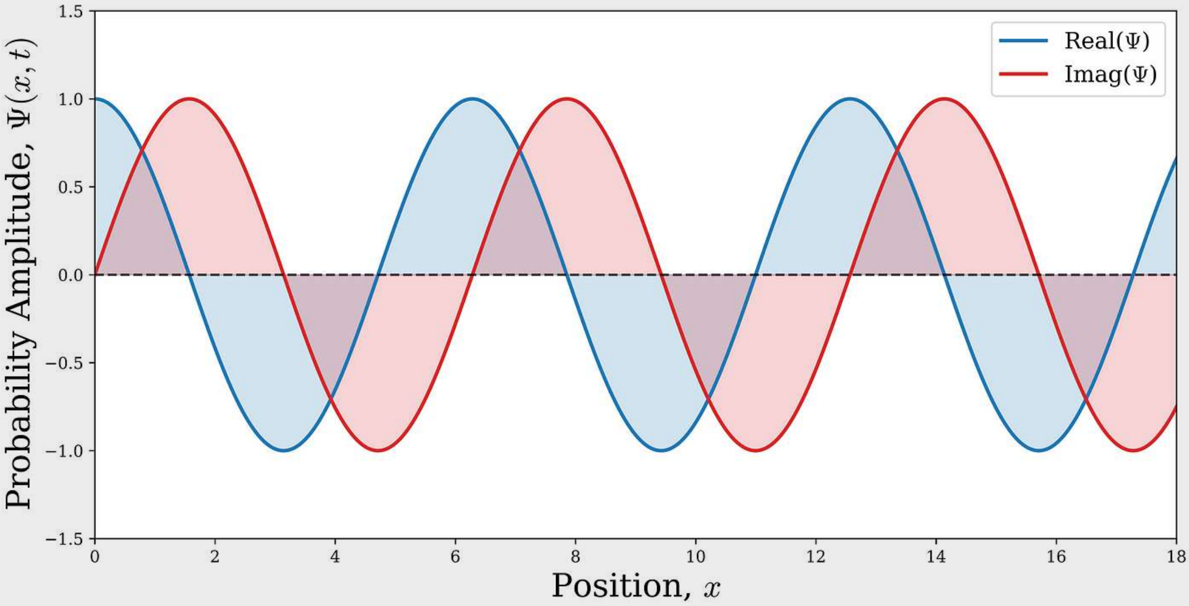
1803

Young demonstrated that light behaves as a wave by showing interference patterns when light passes through two closely spaced slits. This was a crucial experiment that supported the wave theory of light, challenging Newton's earlier particle theory.



1932

Erwin Schrödinger revolutionized quantum physics in 1926 by developing wave mechanics, a mathematical framework that described particles not as discrete points, but as wavefunctions—mathematical entities that encode the probability distribution of a particle's position and momentum. His famous equation, the Schrödinger equation, is a cornerstone of quantum mechanics. It elegantly combines the principles of wave theory and quantum mechanics to describe the evolution of quantum systems over time.

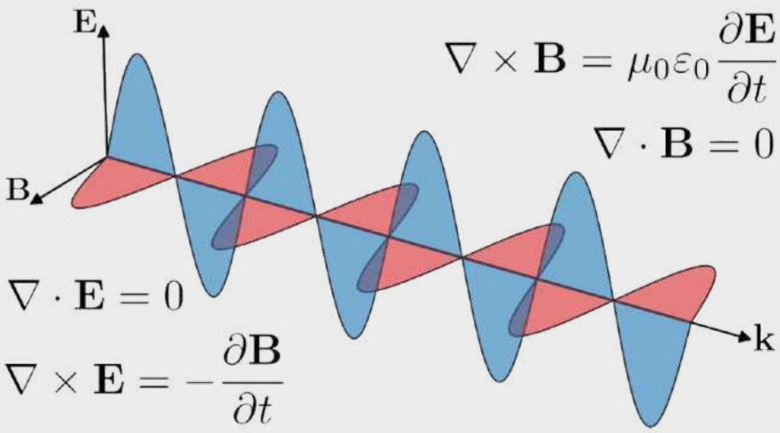


1864

James Clerk Maxwell's groundbreaking work in the mid-19th century revolutionized our understanding of light and its nature. By formulating a set of equations, now famously known as Maxwell's equations, he unified the phenomena of electricity and magnetism into a single theoretical framework. His equations predicted that oscillating electric and magnetic fields could propagate through space as waves, giving rise to what we now call electromagnetic waves. Maxwell identified light as a specific range of these waves, with wavelengths visible to the human eye.

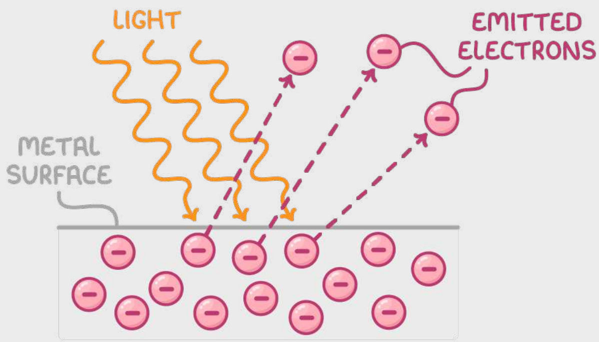
1900

Max Planck proposed that energy is quantized, emitted or absorbed in discrete packets called quanta. This marked the beginning of quantum theory and introduced the idea that wave-like phenomena could exhibit particle-like properties.



1905

Albert Einstein explained the photoelectric effect by proposing that light consists of discrete packets of energy, called photons, with particle-like properties. This revolutionary idea earned him the Nobel Prize and brought particle theory back into focus.

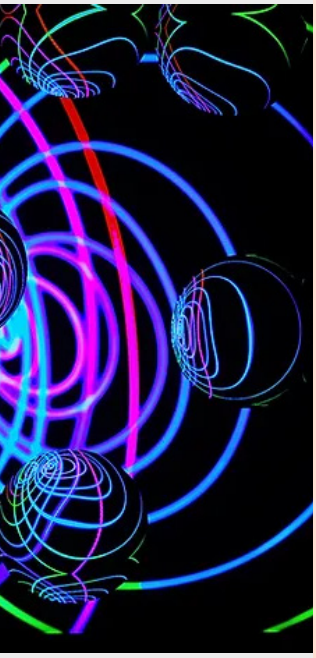


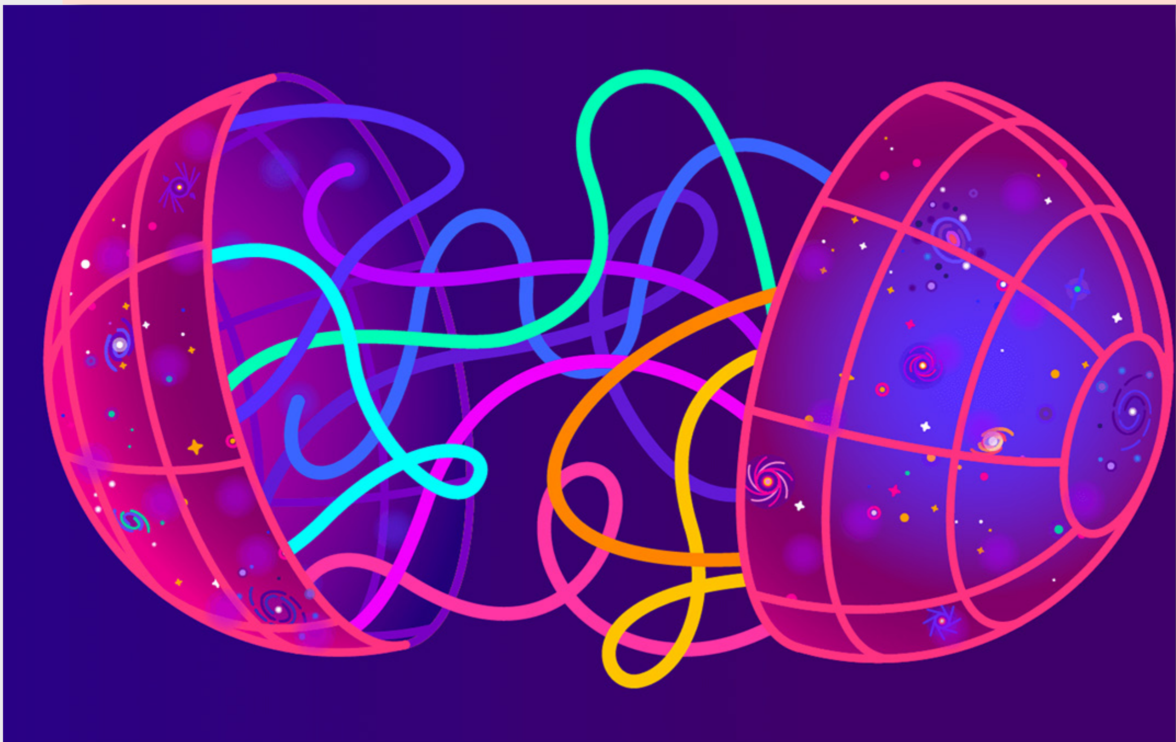
Grand Unified Theory

In the polarised world of physics where few believe in find none of their dear laws applicable in the bewildering world of quantum physics. However, the scientific community uncovers new chapters in the universe only with the quest of the GUT(Grand Unified Theory) etched in its curious mind.

Mankind has been exploring the area around it for centuries, be it expanding to new horizons aboard ships or new planets on space shuttles. However, as we learn about them the sense of sentience kicks in and forces us to find answers to these phenomena deeming us responsible as conscious beings to explain our very existence. The GUT(not to be confused with the biological one) is the embodiment of our sense of responsibility to explain everything simply. Thus, in retrospect if we look at it we realise that we have explained quite a number of things through our unequivocally strong mathematics. However, it seemed the need of the hour for scientists to branch out schisms of mathematics that deal in such abstract sense, they practically of no use to humans.

Thus, humans have felt a need to have a theory and an equation that explains everything without giving rise to the need of diversifying mathematics more and investing more and more human capital to understand such abstract mathematical concepts. Since the Newtonian era we have embarked on a race to the development of our mathematical temperament at par with the discovery of new phenomena. Instances can be seen from the initial Calculus to the present Hamiltonian functions and equations. This theory will explain everything ranging from why black holes lose mass to the credibility of the Big-Bang Theory.In fact, efforts in this direction had been made by Einstein himself as he tried to explain quantum phenomena as it was quite a popular theory back then, thanks to Heisenburg for shaking it up with Uncertainty and Max Planck attempting to stabilise it with the principles of Quantisation. Similarly, Stephen Hawking in his book, ‘ Brief History of Time’ explains the importance of this infamous theory. Even though Einstein failed he laid the cornerstone for the arena of showdowns between Physics and Mathematical concepts that claim themselves as the harbingers of the GUT. Moreover, as we try to develop singular concepts an attempt of this sort was quite successful in the seemingly small realm of quantum mechanics. This effort was the closest to the GUT and thus garnered itself the name the Great Unification Theory.

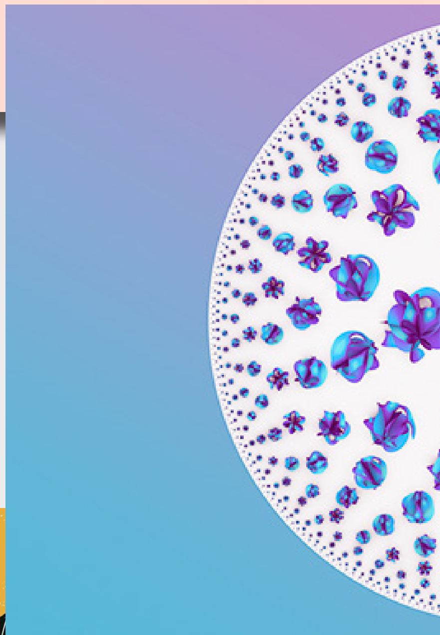


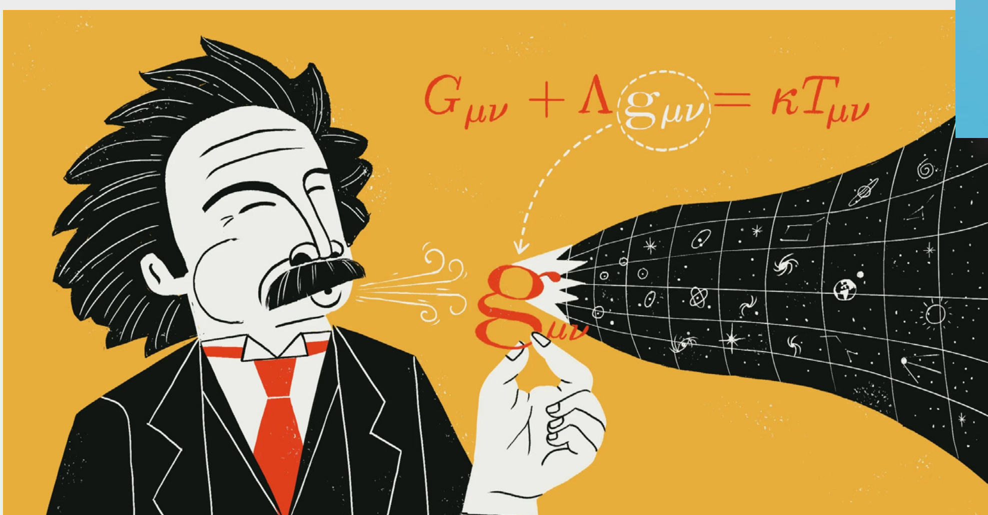


Introduction

The QFT is a theory combining quantum mechanics and special relativity, involving particles being treated, not like point-like objects independent of one another, but rather perturbations or "excitations" in fields filling all space. Each field has one particular kind of particle: an electron is a disturbance in the electron field, a photon a disturbance in the electromagnetic field, etc. This captures the wave-particle duality of quantum mechanics, in which particles exhibit properties of both waves and particles.

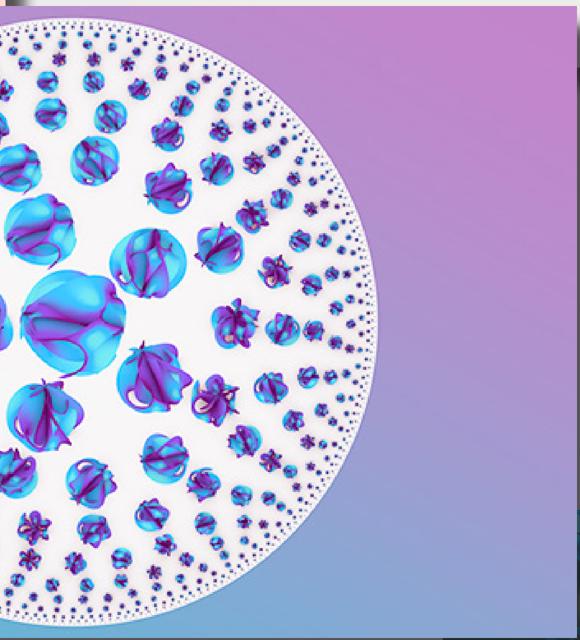
In QFT, the graviton is a hypothetical quantum particle arbitrating gravity in the same way that photons mediate the electromagnetic force. It would be massless and spin-2, which coincidentally aligns with the description of gravity in general relativity. Since gravity is much weaker than all the other forces, detection of gravitons that were supposed to transmit gravitational interactions would be very difficult because it would interact with matter at only a very minimal extent. However, the theory of the graviton finds a central place in the theories of quantum gravity aiming to unify gravity with all other fundamental forces within a quantum framework.

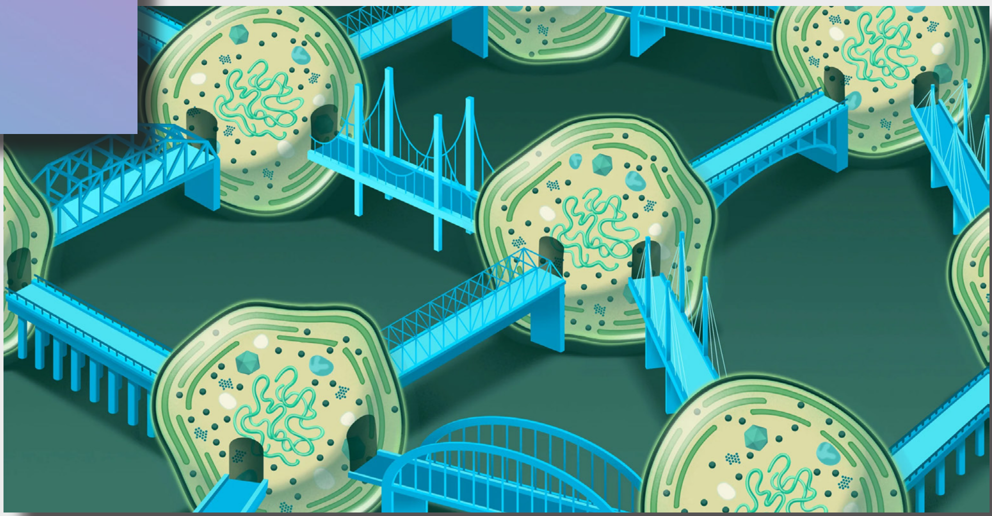




Applications

- Particle Physics: Forms the basis of the Standard Model, explaining fundamental particles and forces.
- Quantum Electrodynamics (QED): Describes light-matter interaction, critical for lasers, semi-conductors, and medical imaging.
- Quantum Chromodynamics (QCD): Explains strong nuclear forces, essential for nuclear energy and neutron star studies.
- Condensed Matter Physics: Models phenomena like superconductivity, quantum Hall effect, and topological insulators.
- Cosmology: Explains early universe expansion, black holes (Hawking radiation), and dark matter theories.
- Quantum Computing: Provides insights into qubit behavior, entanglement, and quantum error correction.
- Particle Accelerators: Predicts outcomes in high-energy experiments like those at the Large Hadron Collider.





“Somewhere, something beautiful is waiting to be discovered” -Carl Sagan

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