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LETTER FROM THE EDITORS

Whether it's powering our home heating systems with natural gas or providing the raw lumber to press into the paper we print our homework on, the natural environment is inextricably tied to contemporary human life. However, as a consequence of rising greenhouse gas emissions, rising average global temperatures are rapidly altering habitats at a rate too quick for evolution to keep pace with. Consequently, our world is confronting reduced crop yields, species extinction, and even increased torrential rainfalls here in New York City.

Our Features topic, "A Future of Sustainability," explores promising pathways in the field of environmental science., delving into emerging solutions by which global citizens might be able to slow the rate of anthropogenic environmental damage. Writers have covered novel energy extraction tools like artificial leaves, an emerging procedure that could turn plastic waste into soap, and even a theory that might allow scientists to assist species in evolving faster to adapt to new climates. In addition to the Features section, this issue will showcase articles reflecting on recent scientific discoveries in Biology, Chemistry, and Physics.

We would like to thank the writers, editors, and layout designers who have made the publication of this issue possible. Furthermore, we deeply appreciate Ms. Woolford and Ms. Doellman for their patience, diligence, and care for each of these articles.

As readers dive into the fascinating articles of this issue, we urge them to share the discoveries, ideas, and findings presented by Spectrum's writers with others and to stay curious in their continual pursuit to further understand the frontier of scientific discovery.

Sincerely,

Joann Yu *Elise Kang*

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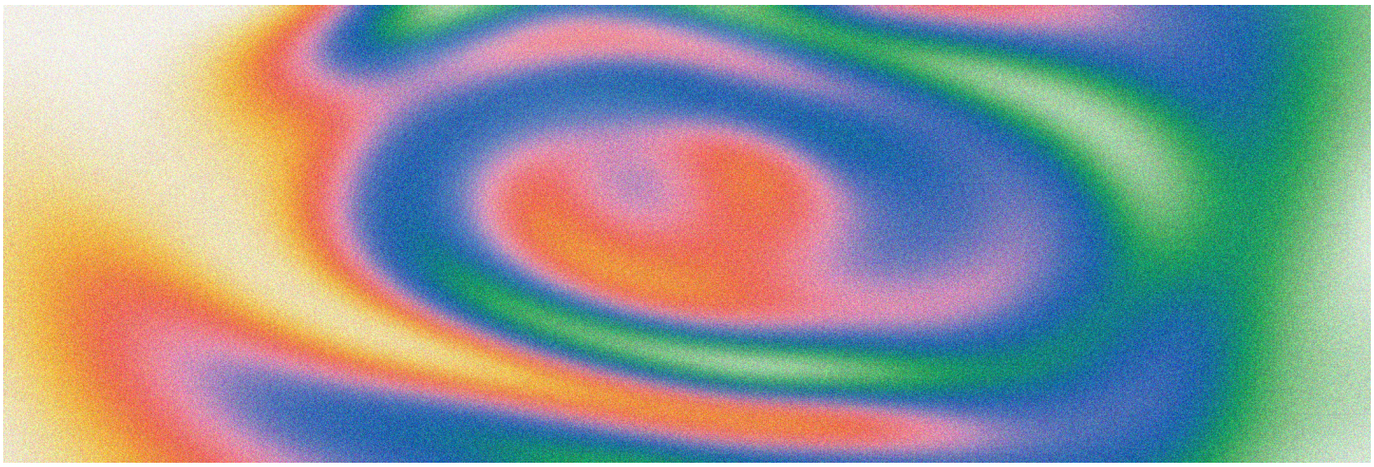

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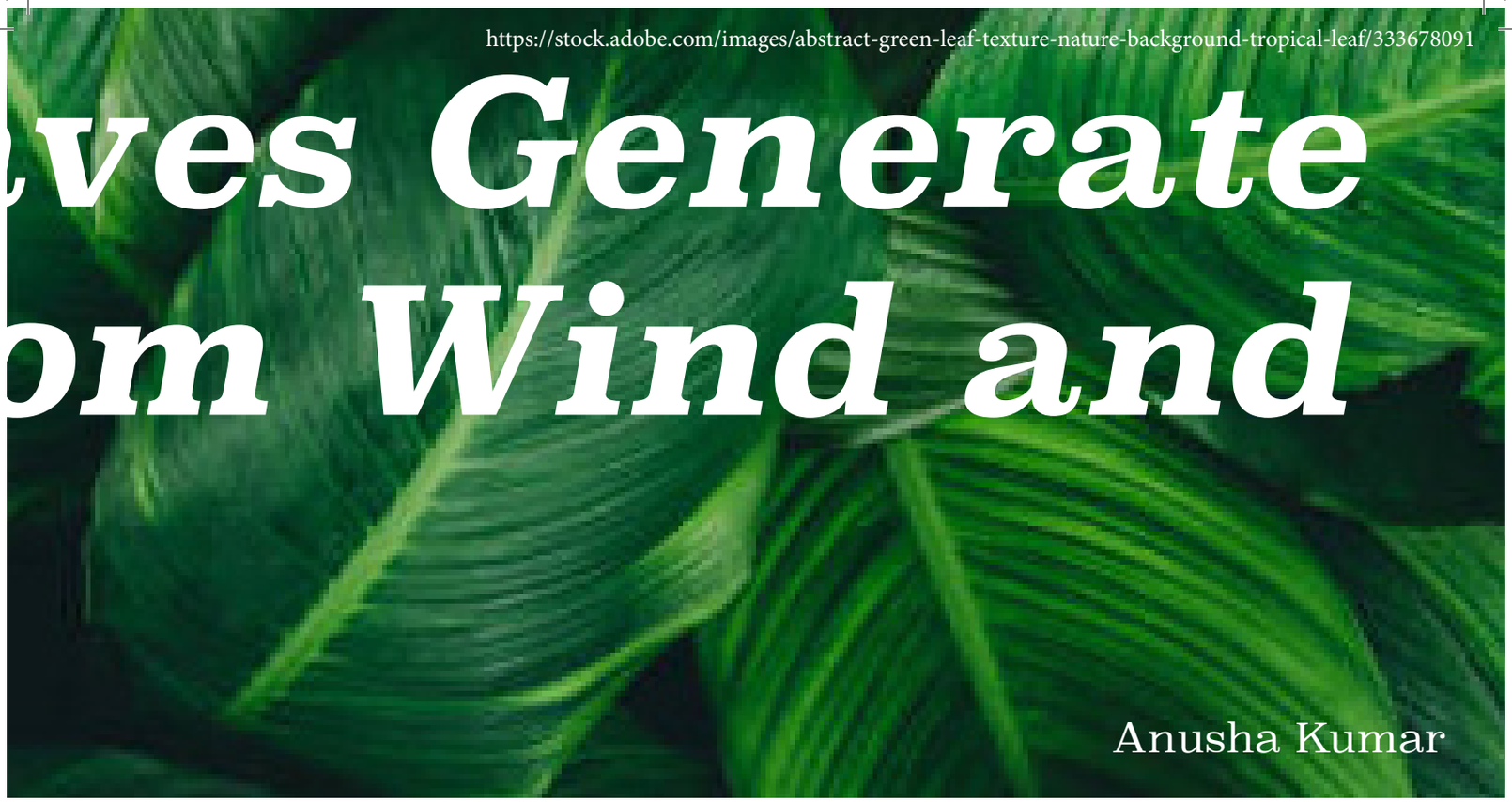
Synthetic Lea Electricity fro Rain

The World Health Organization projects that climate change will cause over 250,000 additional deaths annually (Climate Change, 2023). Consequently, the issue tends to draw attention from people across the United States who demand immediate action. The most popular forms of renewable energy are solar power, wind power, and hydropower. Unfortunately, all of these methods of generating electricity have downsides, including cost and harm to the environment. However, there are new innovative forms of renewable energy that do not have the same downsides as the traditional green technology. An example of this is the multi-source energy harvester that can harness energy from a triboelectric nanogenerator (TENG) and a droplet-based electricity generator (DEG).

Most current forms of renewable energy utilize only one source, such as the sun or wind. However, the multi-source energy harvester harnesses energy from both the rain and the wind, which maximizes efficiency and potential output of energy. The technology consists of tiny, leaf-shaped devices, which are placed on an artificial plant. These are commonly referred to as "power plants," which harness the energy from the wind and rain (Min et al., 2024). The engineering and design of these power plants creates a unique structure which causes the motion from the wind and rain to make the internal parts of the metallic leaves touch, generating a current.

The first of the two parts of the multi-source energy harvester is the triboelectric nanogenerator, or TENG, which harnesses energy from the wind. TENG consists of nylon nanofibers between polytetrafluoroethylene, also known as Teflon, and copper electrodes (Artificial 'power plants', 2024). When it is windy, the layers of the TENG press together, generate static charges, and convert those charges into a current, which creates usable electricity. The TENG works well for this leaf-based technology because of its innate characteristics: flexibility, simplistic design, and wide structural choices (Kim et al., 2021). Furthermore, the material of the TENG is biodegradable and recyclable, which decreases its environmental costs.

The second part of this technology is the droplet-based electricity generator (DEG), which harvests energy from the rain. This technology consists of Teflon, which is waterproofed and covered in conductive fabric that acts as electrodes. The DEG generates electricity when the raindrops hit the electrodes, which causes an imbalance of charges, and results in a small current and high voltage, which is converted to electricity (Artificial 'power plants', 2024). The DEG is key to the power plantes because it combines the triboelectric charging and the hydrophobic effect. Triboelectric charging describes the process of transferring electrons, or charging, through rubbing or friction (Triboelectric Charging, n.d.). The hydrophobic effect is a phenomena observed in lotus leaves where the leaves



ves Generate om Wind and

Anusha Kumar

repel water, and this technology mimics that. Studies have found that the coupling of these two processes leads to significantly high and rapid energy outputs (Min et al., 2024).

Recently a new development was made in finding the optimal water droplet height to obtain maximum energy. Optimal conditions for these technologies take into account the water droplet height, wind speed, force applied, and orientation. Optimal conditions result in a maximum of 113 volts and 67 μA from the DEG and 252 volts and 57.6 μA from the TENG, but only for short periods of time (Min et al., 2024). Scientists implemented four of these synthetic leaves in a commercial artificial plant and measured the output energy of wind and rain from the synthetic leaves. The resulting maximum voltage and short circuit current was 67.5 V and 10 μA and 12 V and 1.75 μA for the DEG and TENG respectively (Min et al., 2024).

There are several applications of this technology in an increasingly digitized world such as digital agriculture, smart homes, and the Internet of Things. Researchers have stated that this "power plant" technology has the potential to expand into larger networks of plants to produce clean energy from natural and renewable sources (Emir, 2024). This would mean that the plants have the capability to replace electricity sources such as fossil fuels or even solar energy. Scientists have found that this multi-source harvesting technology represents a significant advancement in the field of green energy and could work to supply the high demand for sustainable and eco-friendly energy (Emir, 2024).

Furthermore, these "power plants" are better than other renewable alternatives when it comes to environmental effects. The materials that make up the TENG and DEG are environmentally friendly, durable, lightweight, but most importantly biodegradable and recyclable (Min et al., 2024). Other renewable energy sources such as solar power, contain heavy metals, such as lead, which leads them to be classified as "hazardous waste" by some governments, including the U.S. (Atasu et al., 2021). Solar technologies, and other green technologies, are often difficult to dispose of and there is little incentive for innovation in the manufacturing process because the technologies are so expensive. However the "power plant" technology does not have a large negative impact on the environment because it is sustainably sourced and has a clean disposal process.

Ultimately, more research needs to be done to increase the energy output from wind and rain.The leaves could also be made more accessible by decreasing the cost and producing them on a larger scale. Although this technology is very new, scientists have articulated its potential as a key mechanism in the transition away from fossil fuel energy sources towards renewable energy sources.

Cleaning up our act: converting single-use plastics to soap

Zach Hornfeld

In 2023, global plastic production reached a new high of 2.3 billion tonnes, a figure projected to rise to 3.8 billion by 2050 (UNEP, 2024). While this marks continued economic growth, it also means higher amounts of plastic waste will accumulate in landfills, increasing its chances of straying into the environment. As the consequences of pollution become ever more tangible, from damaged ecosystems to tainted human food sources, chemists are focused on finding ways to effectively repurpose plastic as feedstock for valuable, sustainable compounds.

The traditional plastic recycling method—known as mechanical recycling—is currently used to repurpose old plastic to manufacture an array of new products, from carpet fibers to bottles. First, recycling facilities collect plastics from local recycling programs and sort them based on their unique chemical compositions. After the plastics are washed, machines either shred the materials into flakes or melt them into pellets, both of which can be used as raw materials for future plastic products.

While traditional plastic recycling may sound relatively straightforward, it has its limitations. According to the UN Environment Programme, only a fraction—less than 10%—of plastic is given a second life through recycling due to the challenging chemical compositions of the other 90%. Mechanical recycling also frequently downgrades the plastic's quality through a process called downcycling, where the recycled product, having picked up contaminants, is of lesser quality than its original counterpart. As a result, plastic can only be recycled two to three times before the quality is too poor for it to be of any use.

Furthermore, traditional recycling cannot be applied to every kind of plastic. From polyethylene (C_2H_4) , the most commonly manufactured plastic, to nylon (C12H22N2O2)n, each variant has a different composition responsible for its unique properties. This makes it even more difficult to create a sole mechanical recycling technique capable of treating all variants. More durable plastics—like polyurethanes from spray-foam insulation, car interiors, and water-resistant outerwear—as well as polyethylene don't melt down and cannot live a second life. This is due to their crosslinked structure, where C-H bonds are broken, allowing the carbons to bond covalently to the hydrogen of another polymer. Even if all plastics were to be mechanically recycled, nearly 70% would remain untreated globally due to their structures.

A growing number of single-use plastics are skipping recycling entirely, instead being sent to incinerators to be converted into electricity. These facilities burn plastics in huge ovens, collecting the heat to turn into high pressure steam, which is sent through a pipe. The pipe's turbine rotates as steam moves past, generating an electrical current which distributes through the electric grid. In the process, they release a plethora of toxic chemicals and greenhouse gasses, usually outweighing the benefits of decreased plastic waste and meager amounts of energy generated.

Given the need for a sustainable technique that converts a diverse range of plastics into high-quality consumer products, chemists have turned to an entirely different method: chemical recycling. Through this promising approach, used plastics are broken down into their most basic building blocks, which can then be used to create untainted, virgin-equivalent plastics or entirely new chemicals altogether.

In the August 2023 edition of Science, Virginia Tech researchers published what they believe to be a promising breakthrough. The majority of plastics are chemically similar to fatty acids—both are made up of long hydrocarbon chains, which is one of the main ingredients in soap. Noticing this similarity, Dr. Guoliang Liu, an associate professor of chemistry at the university and leader of the study, suggested it should be possible to convert polyethylene, a packaging polymer, into fatty acids and then into soap.

However, Liu and his team faced the challenge of mitigating the size difference between polyethylenes

and fatty acids. Molecularly, polyethylene chains are considerably large—sometimes 3,000 carbon atoms long—whereas fatty acids are much smaller. The solution came to him when he least expected it to. "It was Christmas. I was watching the fireplace," he said.

For any chemical reaction, increasing temperature increases the average speed—the energy—of the reactant molecules. Once a certain temperature is reached, they can overcome the bonds holding them together, thus reducing the size of the polymer.

The first part of the conversion process is depolymerization. The researchers built an oven-like reactor that could be used to safely burn plastic to break it into its monomers, a process known as pyrolysis. Still, they had to be careful not to administer excess heat. As the number of molecules moving fast enough to depolymerize increases, so will the rate of reaction. In the experiment, this meant the polymer chains would be overshortened, yielding an undesired compound.

To counter this, the temperature at the bottom of the reactor was made hot enough to break the polymer chains, while the top was cooled low enough to prevent excessive breaking.

The second stage is surfactant synthesis. Collecting the residue from the reactor, researchers found the product they had created was short-chain polyethylene, a type of wax. Through a series of chemical reactions, they converted the sodium hydroxide collection to soap.

Liu views his project as an immense success. "It's the first soap ever made from plastic in the world," he said. "It has a bit of a unique color. But it works."

However, there are still challenges to overcome. Chemical recycling, a process that champions environmental sustainability, requires a significant energy input, which can contribute to further air pollution. Large-scale implementation also requires efficient methods for collecting, sorting, and pretreating plastic waste before conversion.

While chemical recycling of plastic waste into surfactants is still in its early stages, the potential benefits are undeniable. The method works on polyethylene and polypropylene, the two most common types of plastic. Together, they comprise about half of all plastic waste—some 200 million tonnes per year. More significantly, the method works on "end-of-life" plastics, which would be unrecyclable by mechanical means and would have otherwise ended up in landfills.

Having designed his method for easy use on the industrial scale, Liu hopes that in the future, there will be more collaboration between environmental sustainability research and polluting industrial sectors to effectively combat plastic pollution. Of course, such scientific advancements must be combined with reduced plastic production and use to be most effective.

https://www.theguardian.com/environment/2023/aug/10/scientists-turn-old-plastic-into-soap-polyethylene-fatty-acids-pollution

Empowering Evolution: Harnessing Hybridization to Weather Climate Change

Sarah Korff

Human industrialization has led to increasing levels of carbon dioxide (CO2) levels, causing us to rapidly approach a point where the environment is changing at a pace with which natural selection can't keep up. Though people are responsible for this acceleration in environmental change, humans are now pursuing the potential of unnatural selection, otherwise known as assisted evolution, with the hopes of giving the most vulnerable species a fighting chance. Prior to human interference, genetic variation was the key to evolution. When an environmental change, or a selection event, occurred, there would exist at least one individual that was best fit for the new environment thanks to a random genetic mutation or gene flow. Then, the surviving individuals reproduced and passed their genes onto their offspring, increasing the frequency of the advantageous trait in the population. As a result, future generations would be more adapted to survive in the new environment. Unfortunately, in some species today, the frequency of the mutations and gene flow that enable genetic variation is less than the frequency of human-induced selection events. So, when the environment inevitably continues to change at the hands of humans, the species will not be capable of adapting fast enough and will likely go extinct(Proceedings of the National Academy of Sciences). To reduce vulnerability to the threats of climate change, scientists have turned to a novel approach to assist evolution: artificial hybridization.

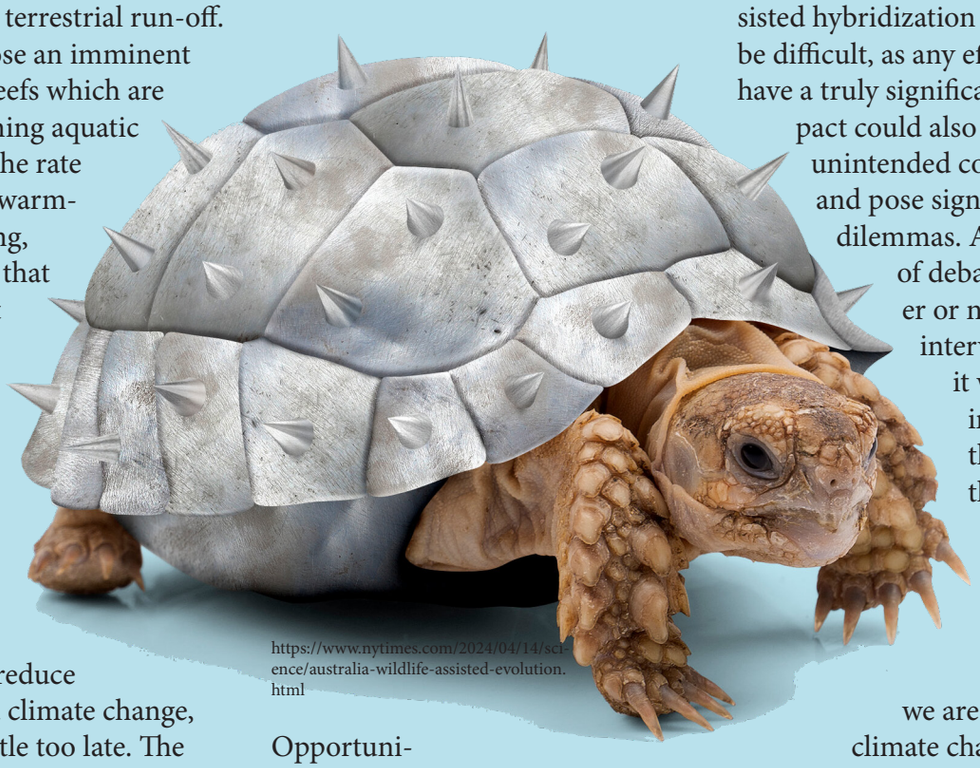
While climate change-related selection events often manifest themselves as severe weather changes, they can sometimes be hidden within the guts of cute but pesky toads. Beyond global warming, climate change can have less obvious consequences, including the destruction of ecosystems by certain invasive species, such as the poisonous cane toad, which arrived in Eastern Australia nearly a century ago. Since then, the native northern quoll, a small marsupial predator which eats the toads, has fallen victim to the toxic amphibians, with entire populations dying out. As the cane toads continue to expand westward, scientists have found that the surviving quoll populations in the east had evolved to possess a

distaste for the poisonous toads. Furthermore, when toad-adverse quolls were interbred with toad-naive quolls, the offspring were found to possess the same protective dislike for cane toads as their toad-averse parents.

Ben Phillips, a population biologist from Curtin University, decided to move some of the toad-averse quolls from the east to the west. By hybridizing quoll populations from the two regions, Phillips hoped to give the western quolls an opportunity to adapt before the toads forced them into extinction. The experiment was promising at first - the two species interbreed, and the advantageous allele, which was the distaste for the poisonous toads, was more frequent in the subsequent generation. The adaptation of the hybridized quoll populations proved that mild human interference can tangibly "assist" evolution and reduce a given populations' susceptibility to climate change. However, in an example of the environment's unpredictability, both a

wildfire and a cyclone hit the newfound quoll population, rendering the species extinct and abruptly ending the experiment.

Nevertheless, there have been other attempts at bolstering species' resilience to climate change through hybridization, such as that of coral reefs. Over the past century, climate change has hit marine ecosystems specifically hard, due to abnormally high sea surface temperatures, cyclones, destructive fishing, and terrestrial run-off. These factors pose an imminent threat to coral reefs which are vital in maintaining aquatic ecosystems. At the rate at which global warming is accelerating, scientists worry that coral reefs won't be able to adapt independently in order to survive climate change on a global scale. Although there are, and must continue to be, efforts to reduce human-induced climate change, it is likely too little too late. The time has now come to address the consequences of climate change in addition to limiting further human contributions to it. To fulfill this responsibility, coral restoration efforts have utilized interspecific hybridization, or the interbreeding of distinct species, to enhance climate resilience. When two species pairs of Acropora from the great barrier reef were crossed in a study conducted by Patricia Mendevez, Lesa M. Peplow, Ary A. Hoffman, Wing Yan Chan, and Madeleine J.H. van Oppen, hybrid offspring better withstood effects of climate change—like higher temperatures and increased CO2 levels—than purebred offspring. Not only did the hybrid offspring survive longer, but they also had higher fertilization rates, proving that hybrid coral populations are more fit for the inevitable environmental changes that are fast approaching(Interspecific Hybridization May Provide Novel Opportunities for Coral Reef Species). While this experiment did not have large scale impacts, it illuminates the potential hybridization has for bolstering coral's and other species resilience to climate change, if humans were to assist.



https://www.nytimes.com/2024/04/14/science/australia-wildlife-assisted-evolution.html

If hybridization seems like the perfect solution, why isn't it already being applied to its full capacity? From a conservation perspective, many biologists argue that hybridization poses a threat to distinct lineages and biodiversity. If we are hybridizing a species to save it, but in doing so we eliminate the distinguishing traits of the species, then has the species really been saved? Supporters of assisted evolution argue the opposite, claiming that a species with different traits is better than an extinct species, which may be the unfortunate reality for millions of species across the globe if we don't intervene soon. Regardless, obtaining clearance for an assisted hybridization project would be difficult, as any effort that may have a truly significant positive impact could also have significant unintended consequences and pose significant ethical dilemmas. Another topic of debate is whether or not we should intervene at all, as it was human intervention that brought the world to its current declining state. Opponents simply argue that because we are responsible for climate change, it is our responsibility to now intervene again to compensate for the damage we have caused to the environment. The common denominator in every argument, unfortunately, is the acknowledgment that climate change is a real threat to the Earth and its species. Can we as humans evolve our mindsets so that other organisms can evolve at the rapidly increasing pace of climate change?

Targeting annexin-A1 can halt cancer cell growth:

New study shows effectiveness of first drug to focus on cancer-causing protein

by Aanya Gupta

Cancer is one of the most widespread diseases in the world, projected to affect 2,001,140 people in the United States in 2024. From past approximations, an estimated 1 in 5 people develop cancer in their lifetime, and around 1 in 9 men and 1 in 12 women die from the disease. Cancer begins when cells experience genetic mutations which cause them to grow out of control or not die when they should. As cancer cells continuously divide, tumors begin to develop. When the tumor is very small, it can easily grow due to the oxygen and nutrients it receives from nearby blood vessels. However, as the tumor grows larger, it needs more blood to bring oxygen and other nutrients to its cells. So, cancer cells send signals for the tumor to make new blood vessels, a process called angiogenesis. This allows cancer cells to get into the blood and spread more easily to surrounding tissues and structures by pushing on normal tissue beside the tumor, a process called metastasis.

As the battle against cancer continues, researchers worldwide are persistently seeking ways to treat it. A groundbreaking study by Anglia Ruskin University researchers has made a significant stride in this direction. Their research reveals that targeting a protein called annexin-A1 can effectively halt cancer cell growth, potentially revolutionizing cancer treatment methods.

The protein annexin-A1 has been found to play a pivotal role in various cellular processes. However, it is overexpressed in many types of cancer, promoting tumor progression. This overexpression correlates with lower levels of survival in various cancers, making it a prime target for anti-cancer therapies.

Using this knowledge, experiments were conducted in order to develop a drug that targets annexin-A1 in an attempt to reduce or stop cancer growth. This research was led by Professor Chris Parris and Dr. Hussein Al-Ali at Anglia Ruskin University (ARU) in collaboration with Professor Chris Pepper of Brighton and Sussex Medical School and UK biotech company Medannex; this company produced the MDX-124 monoclonal antibody therapy.

The new study found that MDX-124, which is being developed for use in immunotherapy–a method which uses the cells of one's immune system to recognize and eliminate cancer cells–significantly reduced proliferation across a number of human cancer cell lines expressing annexin-A1. This anti-proliferative effect was instigated by stopping cell cycle progression. Additionally, MDX-124 was shown to significantly inhibit tumor growth in in vivo models of triple-negative breast and pancreatic cancer, indicating that annexin-A1-targeted therapy represents a viable and innovative approach to cancer treatment.

Professor Chris Parris said: "We know that the protein annexin-A1 activates formyl peptide receptors to initiate a complex network of intracellular signaling pathways, which can lead to numerous cellular responses, including tumor initiation and progression. We have demonstrated in this new study that using MDX-124 can reduce cell growth in annexin-A1-expressing cancer cells both in vitro and in vivo, provid-

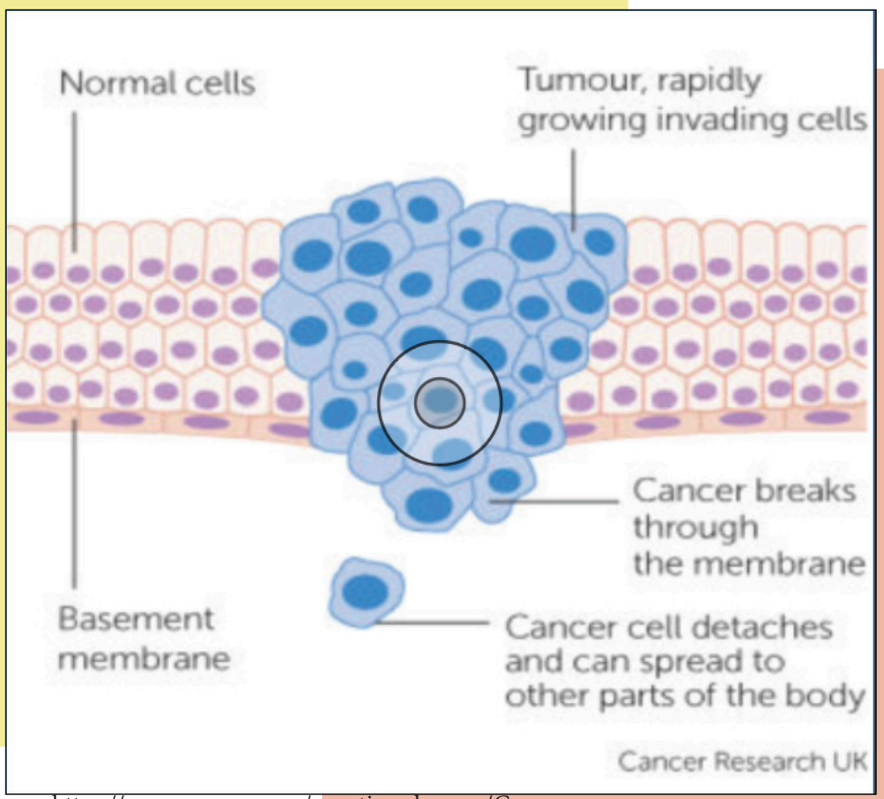
ing further evidence that annexin-A1 is a valid target for therapy in cancer."

Given the significant results of the study, the phase Ib clinical study of MDX-124, called ATTAINMENT, is currently underway to establish the safety and optimum dose of the novel therapy. Its clinical efficacy will then be evaluated in newly-diagnosed cancer patients, in combination with current appropriate treatments.

Although this research is still in its early stages, the results have many significant implications for future cancer treatment strategies. If successfully developed and approved for use, MDX-124 could significantly change the landscape of cancer treatment, providing a more effective and less destructive alternative to current therapies. One example of a destructive therapy is chemotherapy, which involves the usage of a variety of drugs in order to destroy toxic cancer cells. However, in the process, many of the body's nontoxic cells are also killed, which results in more cell death than necessary.

In addition, the study sparks the exploration of other potential targets for cancer treatment. For example, the co-treatment multi-targeting approach in breast cancer cell lines, focusing on inhibiting the purinergic pathway and glucose uptake, has shown promising outcomes. The combination of Dapagliflozin, Paclitaxel, and ARL67156 inhibitors of CD39 and CD73 led to apoptosis, necrosis, and cell cycle arrest, all of which are various processes that result in cell death, and thus creates another potential avenue for cancer treatment.

Medannex Director of Scientific Operations, Dr Fiona Dempsey, who co-authored the paper, said: "We are delighted to publish this work with our collaborators demonstrating the anti-cancer potential of our innovative antibody therapeutic and look forward to the clinical data coming out of the ATTAINMENT study in due course."



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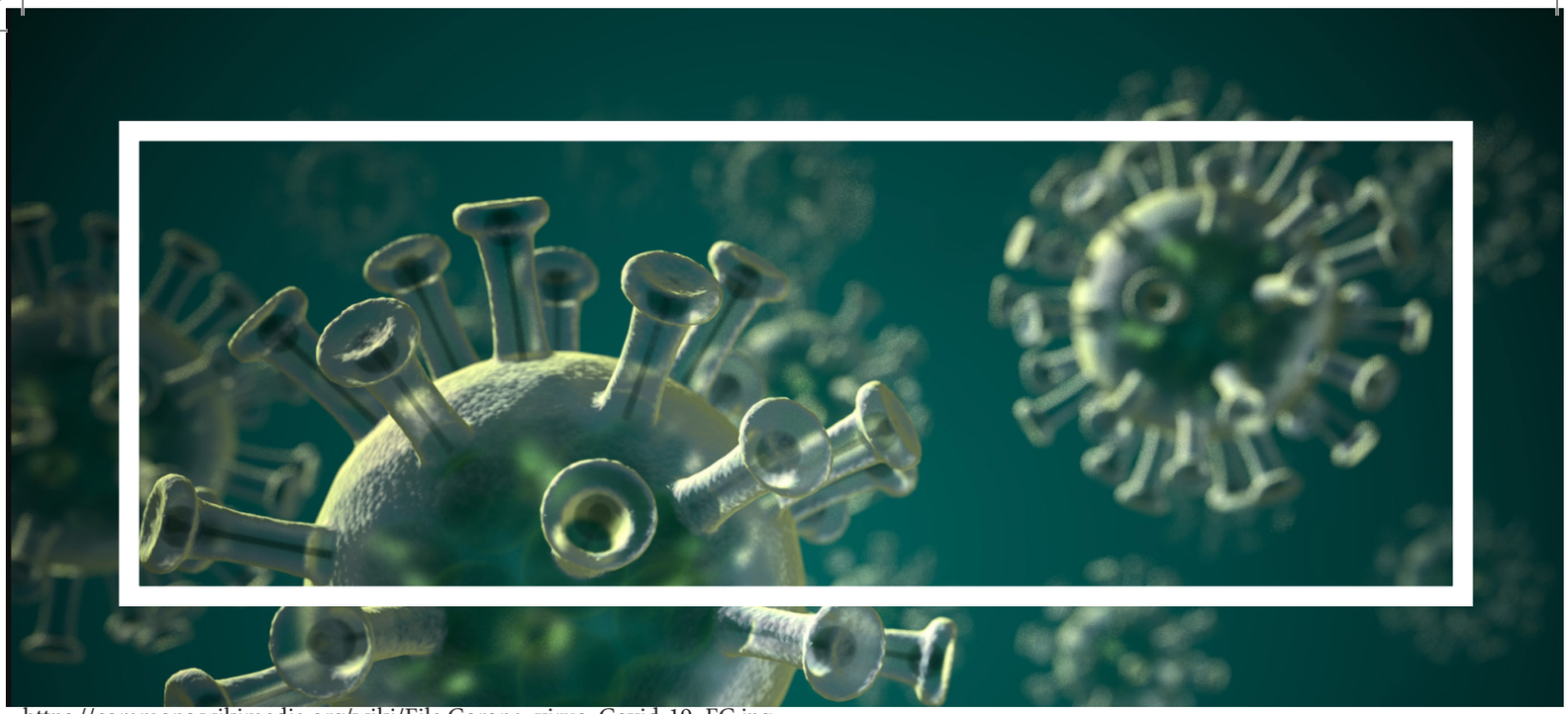

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The Mystery of Long Covid:

Blood Clotting May Be The Answer

By Naina Mehrotra

When the Covid-19 pandemic began in 2020, immunologists were able to mitigate the risk of contracting the virus by quickly developing vaccines. Despite their efforts, hundreds of millions of people have still contracted Covid-19 since 2020. These people have been subject to symptoms such as fevers, coughs, and headaches. Worse, for many, the pain did not dissipate after just a few weeks, instead becoming long-term.

More than one hundred million people worldwide suffer from long Covid, meaning that their symptoms persist after Covid-19 infection. In addition to the common symptoms of regular Covid, long Covid patients often experience symptoms even more debilitating than those associated with acute Covid-19 including brain fog, muscle weakness, low oxygen levels, and depression. These symptoms can prevent some patients from working or even walking just a few steps. Furthermore, it is possible that patients of long Covid have an elevated risk of heart attacks and stroke. Long Covid occurs not only after severe Covid-19 cases, but can also follow more mild or asymptomatic cases. Scientists' responses to long Covid have been varied in terms of timeframe, as research is actively being done; differences between acute Covid-19 and long Covid also contribute to the different rates at which scientists can develop tools to combat these diseases. However, recently the micro-clot hypothesis has gained traction as an explanation of the mechanisms behind long Covid.

Covid-19 is not only a respiratory disease but also affects circulation, specifically blood flow and blood clotting systems. The body utilizes blood clotting to block blood from escaping when a person is injured. To form clots, the enzyme, thrombin, is released by cells nearby to the site of the injury. Then, the thrombin cuts fibrinogen, a soluble protein found in the blood, to form an insoluble protein called fibrin. Finally, strands of fibrin criss-cross to stop the bleeding.

https://spectrumlocalnews.com/nys/central-ny/ny-state-of-politics/2023/05/24/new-york-health-officials-to-end-covid-vaccine-mandate-for-health-workers

Resia Pretorius, department head and research professor in the Physiological Sciences Department at Stellenbosch University in South Africa, discovered that small clots or micro-clots form in the blood of both acute and long Covid-19 patients. She sampled the blood of eighty participants with long Covid, and found micro-clots in all of them. Usually, when clots form, the body breaks them down through a process called fibrinolysis. However, in long Covid patients, these micro-clots resist the process of fibrinolysis, and inflammatory molecules got caught in these micro-clots. Immunologists were able to visualize these micro-clots under the microscope by using dye that fluoresces when it binds to misfolded fibrin.

Caroline Dalton, a neuroscientist at Sheffield Hallam University in the United Kingdom replicated Pretorius's results. Dalton and her team used an automated microscopy imaging scanner to count the number of micro-clots in participants who had never had Covid, participants who had had Covid and recovered, and participants with long Covid. Those who had never had Covid had the least micro-clots, and those diagnosed with long Covid had the most. From this data, Dalton hypothesized that Covid infections create an abundance of micro-clots that slowly disappear as patients recover. However, for those with long Covid, the micro-clots persisted. These results draw upon a 1980s-era hypothesis suggesting that abnormal clotting could explain various symptoms.

It is not clear why these micro-clots form. However, Pretorius hypothesizes that the protein that Covid uses to enter cells might trigger their formation. When she added the protein to the blood of healthy participants, that prompted the formation of new micro-clots.

These micro-clots can be extremely threatening to the human body, possibly resulting in coagulation, the transformation of blood from liquid to gel, and vascular pathology, the reduction of blood flow due to narrowed blood vessels. Consequently, cells experience hypoxia and do not receive enough oxygen. Cellular hypoxia is another explanation for the symptoms that long Covid patients experience.

https://dailymontanan.com/2021/04/26/doctors-scramble-to-understand-long-covid-but-answers-are-elusive/

https://northeastprimarycare.com/covid

Unfortunately, standard pathology tests that measure the molecular content of the liquid part of the blood do not observe any inflammatory molecules because they are caught within micro-clots that are only visible under bright-field microscopes or fluorescence. Although medical professionals face difficulty in diagnosing long Covid, treatment options are emerging.

Research has shown antiplatelet and anticoagulation drugs to be promising treatments of long Covid. Still, there is a danger of bleeding from these medications, and professional monitoring is required. Furthermore, HELP (heparin-induced, extracorporeal, lipoprotein/fibrinogen, precipitation) apheresis, which filters out microclots through a mechanism similar to dialysis, has been shown to positively impact long Covid patients. Still, physicians who perform these treatments are rare, and patients of long Covid often wait months for relief.

In the future, scientists should continue research and clinical trials to clarify the link between micro-clots, hypoxia, and vascular dysfunction in long Covid patients. This research would benefit not just long Covid patients, but also those diagnosed with chronic and viral illnesses who have similar symptoms. Furthermore, treatment for long Covid should be much more readily available than it is today. Patients of long Covid should not have to be in pain for months, awaiting treatment.

EXPLORING DIFFERENT IMMUNE RESPONSES TO VACCINES

by Arshia Rasiwala

https://pixnio.com/free-images/2020/04/28/2020-04-28-10-17-59.jpg

Vaccines are one of the most powerful scientific innovations of the last century, helping to eradicate deadly diseases which were previously thought to be incurable. To create immune memory, vaccines show the body's immune system a pathogenic blueprint of the perpetrator (such as a virus or bacterium) triggering an immune response against the invader. When infected with the real (more powerful) pathogen, the body's immune system will react much faster, increasing the body's chances of survival. Although there is abundant evidence for the benefits of vaccines, most vaccines do not offer the same level of protection from person to person. The immune system is impacted by numerous factors such as genetics, age, biological sex, existing illnesses and microbiomes, hence the differing immune responses in different people. For example, the immune system of an older individual is better at dealing with older diseases but is ill-suited to deal with novel diseases such as COVID-19 because it is not familiar with it. Other examples of these differences include biological sex, as many genes on the X chromosome relate to immunity and differences are being increasingly seen as chromosomal females have stronger immune responses to varying diseases.

Particular studies regarding such factors pertain to a DNA signature found in certain individuals. For example, many children receive

the BCG (Bacillus Calmette-Guérin) vaccine for tuberculosis which was first distributed over a century ago. Researchers believe that the BCG vaccine can be used to treat multiple infections by triggering an "innate," or immediate/nonspecific immune response. Simone Moorlag from the Radboud University Medical Centre and her colleagues conducted a study where the BCG vaccine was administered to 323 adults who did not receive it previously. The results showed that those who had a strong innate immune response after the vaccine had DNA signatures that made the body's immune response weak. Participants who did not have a strong response to the vaccine already had cells alerted to the intruder before the vaccination.

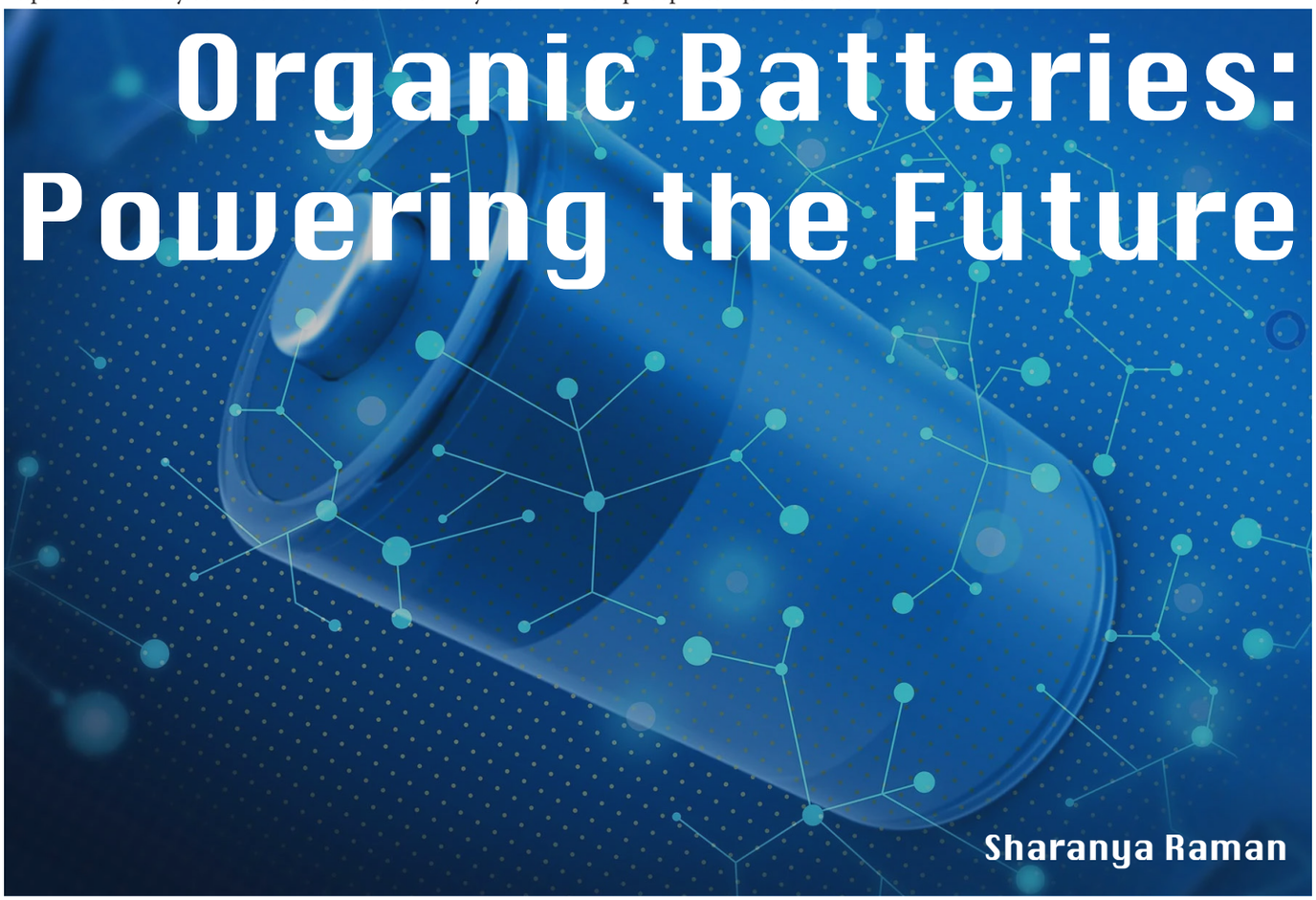
The Human Immunology Project Consortium (HIPC), a network of research institutions studying the immune responses from different infections and vaccines, conducted a study where Emory researchers analyzed the DNA sequences of 820 adults immunized with 13 vaccines. Through this study, the researchers aimed to identify specific biomarkers that generate differing immune responses from person to person. The participants were separated into 3 groups, based on the level of inflammation they exhibited prior to vaccination: high, low and mid-inflammatory groups. The researchers found that the group with the highest inflammation had the strongest antibody response while the lowest inflammatory group had the weakest antibody response. Through the data collected in the study, Dr. Rafick Pierre Sekaly identified specific biomarkers among the high inflammatory group that can predict how well an individual's immune system responds to an infection.

Similarly to HIPC, Many researchers around the world are searching for universal signatures in the genome that correlate to immune responses from vaccines. Researchers from the Yale School of Medicine worked to conduct a meta-analysis of multiple studies to see if there were universal gene signatures present, both pre- and post- vaccination. After compiling a mass of data on the immune responses to many different vaccines, the Yale team came up with a time-adjusted signature. Steven Klienstien, a researcher from Yale described this time-adjusted signature as a similar association of antibody response but one which occurs at different times. Although there were a few slight differences in antibody production among individuals, these differences did not depend on vaccine type, but rather on more complicated factors. In this study, nearly all vaccines work with the results, except for the yellow fever vaccine, since the production of antibodies occurred significantly after other vaccines.

Understanding the pre-vaccine states of individuals allow scientists to simulate stronger immune responses in more vulnerable patients. This work will also significantly improve vaccine development and clinical trials against numerous infections, as scientists can begin to tailor vaccines for each person. Trials for vaccine development will be done in a more efficient and cost-effective manner, saving countless lives in the process. For example, patients that have a weaker immune response will be given an immune enhancer along with a vaccine to trigger high inflammation and therefore produce more antibodies. Through studying the different immune responses people have, scientists will be to improve vaccine response among all individuals.

https://scitechdaily.com/researchers-uncover-why-lithium-iron-phosphate-works-so-well/

Organic Batteries: Powering the Future



Sharanya Raman

Batteries have become a prevalent part of modern-day living, whether that be through powering a car, computer, or even a remote control. While they all have different types of batteries, the essence remains the same. As more of our day-to-day appliances need batteries to function, the sustainability of using them also becomes a pressing issue.

The most commonly used battery in today's world is the lithium-ion battery. Used in every household, this everyday battery, however, has some complicated problems associated with it. In these batteries, the cathode contains cobalt, a metal that offers high stability and energy density. Currently, many ethical and environmental concerns come with its use. As a rare metal, cobalt's price can undergo significant fluctuations, and a considerable portion of global cobalt deposits are situated in politically unstable regions. The majority of cobalt is produced in the Democratic Republic of the Congo, which is infamous for its gross violation of human rights. Due to the exploitation of human rights and the degradation of the environment, the urgency of an alternative becomes increasingly prevalent. Approximately 70 percent of the world's cobalt is produced in the Democratic Republic of the Congo and up to 30 percent of the Congolese cobalt is produced by artisanal and small-scale mining. These issues become extremely urgent as issues with violent ethnic conflict, Ebola, high levels of corruption, Child labor, and even fatal accidents reoccur.

Given the paucity of rare metals and the social issues surrounding them, scientists have been working towards alternate sources and options for batteries and have ascertained that organic batteries offer a promising solution to the increasing cobalt impact. Unlike traditional batteries, organic batteries use carbon-based materials derived from natural sources such as plants or organic compounds. These batteries have proven to be completely environmentally friendly and combat the effects of cobalt batteries. Furthermore, carbon-based batteries are more cost-effective and scalable.

One such advantage of organic batteries is their ability to provide a higher power output while reducing any adverse environmental impact. Organic electrode materials offer high conductivity and stability, enabling faster charging and discharging rates compared to

https://www.sciencenews.org/article/zinc-air-batteries-single-use-new-design-rechargeable

conventional batteries. The batteries utilize organic radical compounds instead of metals, leading to a positive environmental impact. Furthermore, organic batteries can open up the potential for roll-to-roll processing using various printing methods, allowing for the cost-effective production of flexible devices. A study done by ACS publications determines that the cathodes in an organic-based battery have charging rates that are at least 10 times faster. Due to this, their usage range could become much wider. Stemming from a flashlight to an electric vehicle.

While lithium-ion batteries have long been the norm, concerns over their environmental and ethical implications, particularly regarding cobalt extraction, highlight the need for alternatives. Organic batteries emerge as a promising solution, offering not only environmental friendliness but also enhanced performance and energy output. By utilizing carbon-based materials, organic batteries present a compelling pathway toward reducing our reliance on rare metals and mitigating environmental degradation. As society continues to prioritize sustainability and ethical practices, the development and adoption of organic batteries stand as a pivotal step towards a cleaner, more sustainable energy future.

A Fundamental Misunderstanding:

Recent Study Disproves Textbook Chemistry Models

by Alex Tang

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Misconceptions about the fundamental structures that produce the world may contribute to gaps in knowledge and perceived correctness that is perhaps actually false. In environmental science, including fields such as atmosphere and climate studies, one of the most important things to recognize is how water molecules function and collaborate with other molecules at the microscopic level on the surface of the ocean. Since this area of study is of foremost importance, scientists may generalize this study to electrolyte solutions that mimic the structure of ionic interactions that occur within the surface of the ocean. Electrolyte solutions by definition contain ionic solutes such as hydrochloric acid (HCl) or sodium chloride (NaCl) that easily dissociate within water due to their ionic bonds.

Many studies seem to confirm that ions within these solutions situate themselves at the direct surface of the water, which generates specific electric fields that are crucial to understand in detail. These fields directly affect the molecular interactions of the solutions. Therefore, concern arose when a recent study discovered that most ions are actually located slightly below the surface, inducing stratification, or layering, of varying molecular structures. These results restrict the validity of previous models of electrolyte solution interactions at the surface (commonly referred to as air/solution interfaces).

Currently, a vast portion of the research done in this field stems from the usage of various spectroscopic techniques, which often use various light beams to obtain information at the air/solution interfaces. The data collected from these tools may be used within computer simulations called molecular dynamics (MD) simulations - complex tools used to model how particles move at the atomic level - interpreting the fine movements at the air/solution interface.

The most common textbook model that describes the past-accumulated data at the air/solution interface is the electric double layer (EDL) model, where polarizable ions exist directly at the surface, but ions that are less capable of being polarized exist deeper within the solution. The distribution of charge caused by this model is the basis for many descriptions of how electrolyte solutions function in the ocean and in various use cases. However, these spectroscopic techniques may not be able to achieve the rigor required to obtain and interpret highly specific level observations that yield definitive results due to the inherent complexity of particle interactions at the quantum level. Because of this, we had theorized that this current EDL model may not be fully accurate. In other words, the models that we obtain from these experiments may be too

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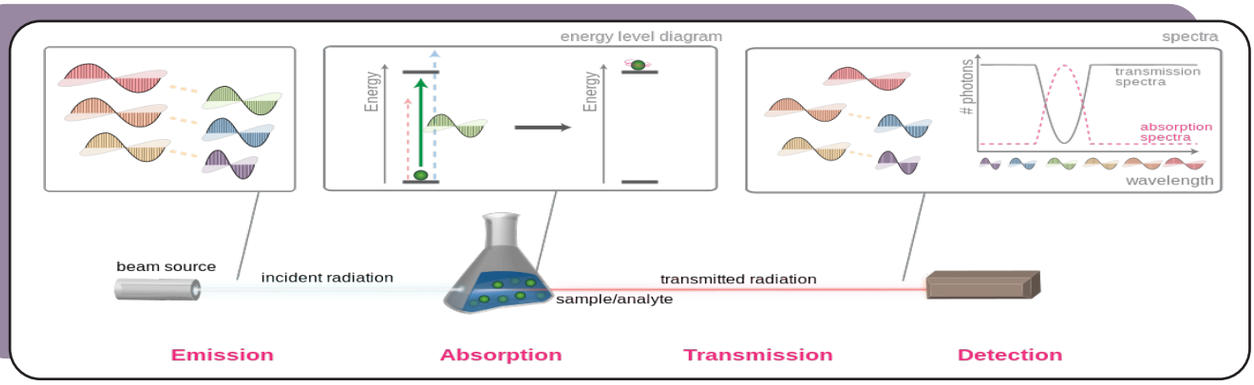
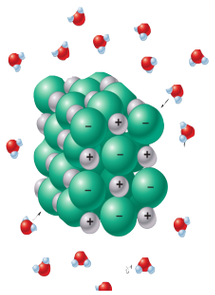


speculative because we have used spectroscopy with a variety of limitations, yet we frequently derive assumptions about the air/solution interface using them.

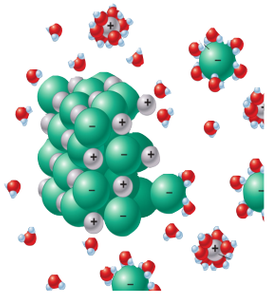
One of the most promising techniques to improve our understanding of the air/solution interface is vibrational sum frequency generation (VSFG) spectroscopy. VSFG spectroscopy is extremely detailed and capable of high level molecular analysis. It is now frequently used to study surfaces and their motions as it can detect specific molecular vibrations at the area of interaction. The technique uses two laser beams of differing light wavelengths that mix at the interface. This mixture of light is the output and is the sum of the two input frequencies. This output carries highly detailed information about the vibrations, orientations, and interactions that occur within the molecular structures at the air/solution interface.

However, while VSFG Spectroscopy is advanced and is the most promising in the area, progress is still restricted. One major roadblock is the necessity for heterodyne detection. Heterodyne detection refers to the complicated techniques that VSFG spectroscopy employs to utilize multiple different frequencies of lightwaves. Such methods greatly induce error, noise, and complexity to the setup. Additionally, sometimes the response that water molecules return via VSFG spectroscopy are featureless and do not contain meaningful data due to the wide range of vibrations that the molecules may display. These complications add to possible ambiguity that the VSFG spectroscopy might encounter.



One study done at the Max Planck Institute for Polymer Research in Germany uses techniques that overcome the roadblocks in VSFG spectroscopy and provides a clear result of the molecular interactions within the air/solution interface in electrolyte solutions. Researchers used high level heterodyne-detected VSFG (HD-VSFG) data, and analyzed it with the extremely rigorous and specific neural network-aided ab initio molecular dynamics (AIMD) computer simulations. AIMD simulations try to accurately predict the behavior of molecular structures based solely on physics and the basic foundations of quantum mechanics, a complex field that attempts to describe how nature behaves at an atomic scale. The term “neural network-aided” explains how certain AIMD simulations are trained on huge datasets of many quantum mechanical equations, that allow the simulation to understand the intricacies of the forces experienced by various atomic configurations using machine learning. These methods are a type of AI (artificial intelligence) approach to predict the air/solution interface, significantly increasing efficiency and accuracy in calculations and modeling. The team used these techniques to determine the behavior of the air/solution interfaces for ten main electrolyte solutions containing HCl, NaOH, CsF, NaF, NaCl, NaBr, NaI, MgCl2, Na2SO4, MgSO4 and NaClO4. Further groups of solutions were created by altering the concentration of the ionic solutes within the solution, to expand the breadth of the experiment.

The team discovered that by comparing the real world data from the HD-VSFG spectroscopy to the simulated data, the previous textbook models of EDL formation may not occur. Combined data from the HD-VSFG spectroscopy and the simulations discover that ions are mostly located on average some ångstroms (1 ångstrom = 10-10 m = 0.1 nm) below the air/solution interface, contradicting the textbook model of direct surface interaction.



This study may seem too insignificant to have any real world implications, as a few ångstroms of difference seems unworthy of this much time and investment. However, it is important to recognize that these current models and understandings now provide a much clearer and more accurate understanding of our basic scientific models. These studies may strike down conventionality in favor of better accuracy. For example, one of the processes that occurs everyday is aerosol formation, or formation of suspended particles within the air, such as clouds or fog. The air/electrolyte interface is a major aspect of aerosol formation, which contributes much to the study of the atmosphere, and of climate science. Due to rapid industrialization, there are major changes in climate in the present day. One of the major concerns in environmental science is the global atmospheric shift to an increasing amount of nitrate aerosols, which are commonly formed from ammonia and nitric acid - chemicals that can be major byproducts generated from the industrial world. By having a better grasp on the scientific models now, and by diminishing the amount of ambiguous and speculative data, we are able to provide more accuracy and efficiency for any future.

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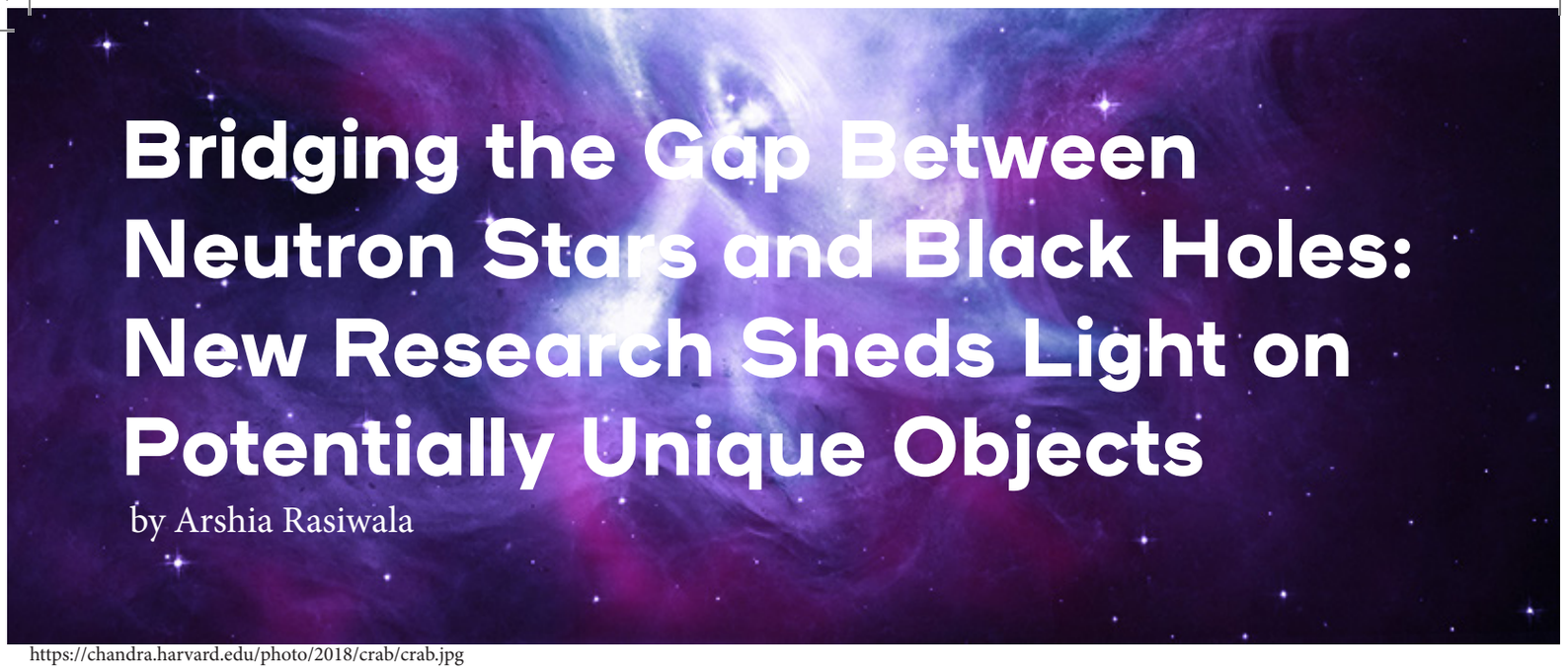

Bridging the Gap Between Neutron Stars and Black Holes: New Research Sheds Light on Potentially Unique Objects

by Arshia Rasiwala

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Between the mass of a black hole and a neutron star, there is something. But what exactly is that something? Luckily, new evidence gathered from a unique star system — a binary with both a neutron star and one of these mysterious objects — may shed some light on what may exist in this so-called "mass gap". Using radio data of the millisecond pulsar binary PSR J0514−4002E, which astronomers collected with the MeerKAT observatory, scientists may have detected one of these objects, a feat made possible by the unique nature of this system.

A neutron star is an immensely compact stellar remnant, created from the deaths of stars 8 to 25 times the size of the sun. Pulsars, a unique type of neutron star, shoot out intense beams of electromagnetic radiation from their poles as they spin. Their spins are usually extremely stable but can deviate when the pulsar is in motion or when their light is bent by a nearby gravitational field, such as that of a companion object. Measuring any deviations in their spin can allow astronomers to measure the properties of these companion objects in orbit around the pulsar. A black hole, on the other hand, is formed from the collapse of stars even more massive than those which collapse into neutron stars. Black holes are so dense that no light can escape them, making them nearly invisible to any direct observation. They can, however, still be detected through indirect means, such as their effects on nearby objects. There is a gap in knowledge of what exists between the masses of the heaviest possible neutron stars (about 2.2 solar masses) and the lightest black holes (about 5 solar masses) formed from the death of a star — the "mass gap". Due to their apparent rarity, as well as the difficulty in observing and determining the characteristics of these objects, their precise nature and formation process are not yet known with certainty.

Searching for millisecond pulsars — a subset of pulsars with an extremely short rotational period of less than 10 milliseconds — astronomers turned to NGC 1851, a globular cluster. Globular clusters are collections of stars far denser than galaxies, and as a result are excellent places for the formation of millisecond pulsars, as the high density of stars makes binary systems far more likely to form. The high rotation speeds of millisecond pulsars are often derived from their interactions with other objects, of which there are plenty in a GC. These binary systems are considered to be highly interesting objects of study, offering numerous opportunities for fundamental physics research. Even less immediately interesting isolated pulsars have been used to conduct highly useful research. The result has been a push to detect more millisecond pulsars. In one study, by surveying the globular cluster NGC 1851, astronomers discovered 13 new millisecond pulsars. To determine the pulsars' characteristics, they conducted radio observations with MeerKAT's Pulsar Timing User Supplied Equipment (PTUSE) instrument. One particular binary system with a high mass caught their eye — PSR J0514−4002E — so they followed up on MeerKAT's observations of it using optical data previously collected by the Hubble Space Telescope.

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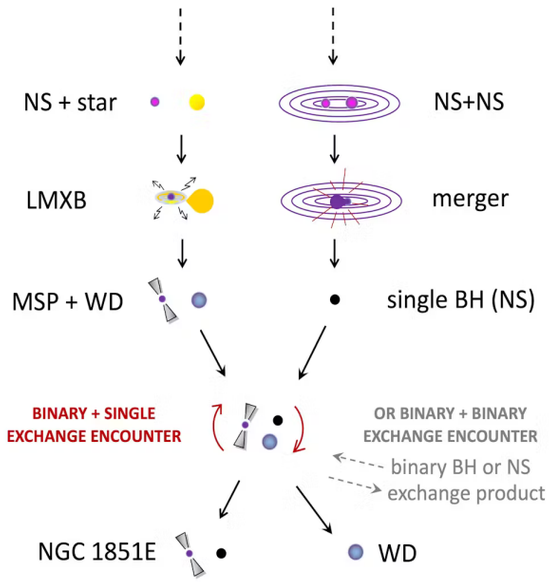
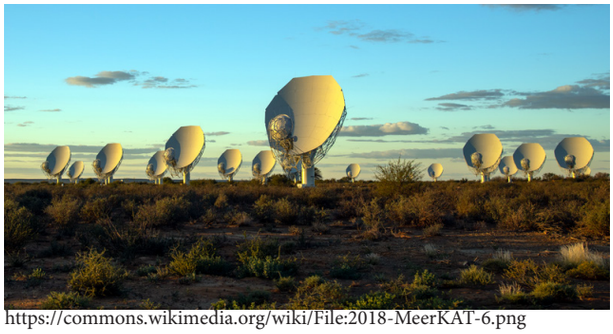
If PSR J0514−4002E's companion were a regular main sequence star, it would have been detectable in this imagery. However, they could not detect it — whatever it was, it was not detectable through direct observation.

Furthermore, the astronomers were able to determine the mass of the system — 3.887 solar masses — and that of the companion, which they inferred must also be a highly compact object, such as a black hole, as they could not directly detect it. In comparison, the highest mass double neutron star system known is an entire solar mass less massive, meaning that, at least according to the current understanding of neutron stars, this could not possibly be a double neutron star system. Additionally, it is also larger than any double neutron star merger ever detected. Assuming an edge-on orbit, where, from the observatory's perspective, the pulsar appears to be in the same plane in which the companion orbits, they determined that the mass of the companion is between 1.84 and 2.71 solar masses, most likely above 2.09. The highest previously measured pulsar mass was 2.08 solar masses, and the smallest black holes are around 5 solar masses. Therefore, PSR J0514−4002E's companion likely falls within the mass gap.



So, what exactly is this object? Scientists have come up with a few possible theories. The first is that it is a black hole, lighter than any we have detected before. This black hole could have been left over from a merger between two neutron stars, which results in black holes lighter than those typically formed through the collapse of a single star. This possibility is made even more likely due to the system's location in a densely packed globular cluster, where neutron star merges are far more likely to occur. This black hole, now an independent object, would be free to wander the globular cluster until it ran into a new binary system, where it would kick out the smaller object and insert itself in its place. This hypothesis is backed up by the characteristics of PSR J0514−4002E and its companion. PSR J0514−4002E may have gained its accelerated spin rate from a mass transfer from a smaller companion, which would likely have evolved into a white dwarf. Upon arriving in the system, the black hole would likely disrupt the system such that the white dwarf would be pushed out, and the black hole would enter an eccentric orbit — which the companion object is in. However, a more complicated explanation for the system, such as one with multiple exchange encounters, is also possible, preventing the nature of the system from being inferred with certainty based purely on binary evolution models.

Understanding the nature of these kinds of objects will patch a hole in our understanding of the universe. If the companion is an object of a type previously unknown, its discovery could greatly change our understanding of matter in the most extreme environments and expand our understanding of the universe. However, even if it is just another black hole or neutron star, the unique series of events necessary to create such a system will further confirm our understanding of the universe and help to refine our understanding of those objects. The astronomers who made this discovery hope to continue their research on it and eventually confirm its true nature, gaining insight into some of the most unique objects in the universe.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Beyond Binary: Harnessing the Power of GKP Qubits in Quantum Computing

by Ellen Wang

In today's world, technology plays a pertinent role in our day-to-day lives. Seemingly everything, from the way we purchase groceries, to the cutting-edge machines used in healthcare, requires some form of technology. However, there are still problems that our modern computers cannot tackle. Classical computers are limited when faced with large-scale computational tasks; the time, power, and efficiency of contemporary machines are unable to keep up with the growing demands of forefront research.

With the development of quantum computing in the mid-1980s (Quantum Computer | Computer Science, n.d.), scientists and researchers alike have developed methods to increase the speed of classical computing, where the unit of measurement and information storage is the bit, which

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle,\ ||\alpha||^2 + ||\beta||^2 = 1$$

exists in a binary state of either 0 or 1. However, the basis of quantum computing is the quantum bit (qubit)—the quantum version of a classical bit. Unlike classical bits, qubits can go into a superposition, or simultaneously be in the $|0$ or $|1$ state. The qubit's state is unknown until it is concretely measured; upon measurement, the wave function of the qubit collapses into the $|0\rangle$ or $|1\rangle$ state (quantum versions of the classical 0 and 1 state) based on a probability, denoted by and in the equation below (Kwak et. al, 2021).

Without measurement, the qubits are in superposition—making their computational power exponentially greater than their classical counterparts.

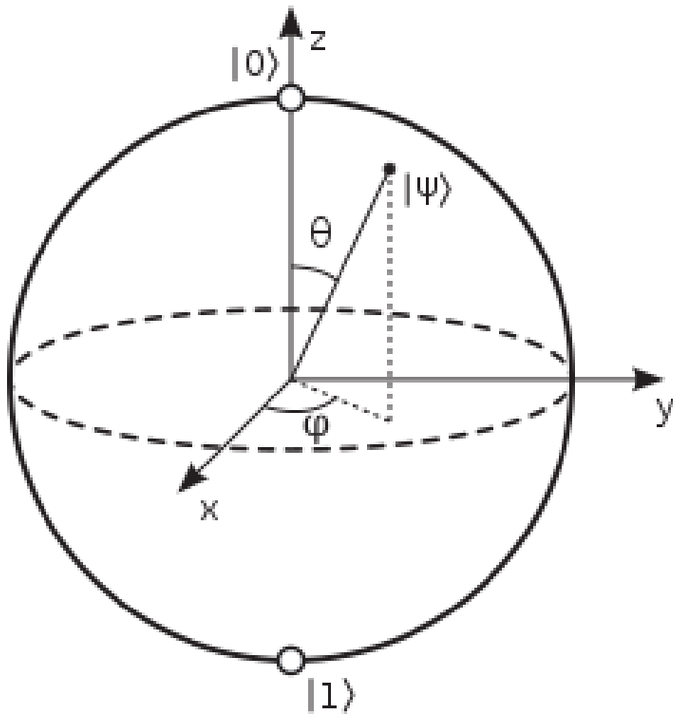

FIG 1. *Bloch sphere depicting the states and positions of a qubit.*

The states of a qubit can be illustrated on a Bloch sphere, as shown in FIG.1 (Bloch Sphere | Prefetch, n.d.), where they can be transformed through rotation around the x, y, and z axes by means of quantum gates or matrix operations, as shown in FIG. 2 (Quantum Computer | Computer Science, n.d.).

Quantum computing is on the brink of a breakthrough to revolutionize numerous domains, including cryptography and cybersecurity, pharmaceutical research, material sciences, artificial intelligence, and many more. Tech giants, including IBM, Google, Alibaba, and many others, are racing to break through and dominate this space (Kim et. al, 2023).

$$R_x(\gamma) = \begin{bmatrix} \cos\left(\frac{\gamma}{2}\right) & -i\sin\left(\frac{\gamma}{2}\right) \\ -i\sin\left(\frac{\gamma}{2}\right) & \cos\left(\frac{\gamma}{2}\right) \end{bmatrix}$$

EQ 1. The equation denoting a single qubit state $|\Psi\rangle$, where $||\alpha||^2$ and $||\beta||^2$ represent the probabilities of observing $|0\rangle$ and $|1\rangle$, respectively.

However, building quantum computers involves immense technological challenges: measurement of qubits is irreversible; therefore, quantum states are intrinsically more fragile and can lose their coherence, or their quantum properties, easily, in a process known as decoherence. Over the past couple of decades, experimentalists have constructed small-scale quantum computers of various types, including superconductors or trapped ions. Even though tremendous efforts have been invested in developing the much-desired quantum computing technology, the ultimate "holy grail" of a scalable quantum computer available for regular users is still far from practically feasible.

One possible solution to the frequent decoherence of qubits in quantum states is the usage of Gottesman-Kitaev-Preskill (GKP) qubits, which exist in GKP states. While traditional qubits exist in a binary spin system like that of electrons or polarized photons, GKP states encode information using continuous variables, such as position and momentum, which allow for error correction and more fault-tolerant systems (Konno et al., 2023).

However, GKP states are extremely difficult to create. Most attempts have utilized optical or harmonic oscillators, with the presence of an electromagnetic field. Squeezing and displacement operations, which shift quantum states in phase space from an initial position to a desired location, can reduce error in certain quadratures, and the two modes are sent through a beam splitter. Yet, this process requires very specific machinery and operations and is unable to be generalized to a wider system.

A recent development in the pursuit of a solution to the engineering obstacle of acquiring precise, powerful, and economical machines was announced in January, where scientists from the Japan Society for the Promotion of Science and the Czech Science Foundation discovered a method for creating GKP states that involve propagating light and homodyne detection (Konno et. al, 2024). Light propagation is the process by which energy is transferred from one point to another. Therefore, the usage of this process takes away the necessity for precise, harmonic oscillators that were utilized previously.

Moreover, the new technology makes use of homodyne detection, without loss corrections. Homodyne detection, in electrical engineering, is the process by which information is extracted by a signal. Because qubits exist in superpositions and are immeasurable without collapsing them and revoking their quantum properties, homodyne detections offer a useful method to utilize qubits without making them "one-use" particles.

With multi-hundred qubit computers being developed by big companies like IBM, if these qubits are able to be used consistently and reliably, the ten-year prospect of making quantum computers accessible for daily use may become a reality. Overall, this new methodology for allowing qubits to exist in favorable states without a high risk for decoherence offers a new avenue for quantum computing research into the future.

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