

LETTER FROM THE EDITORS

Dear Reader,

Behind each scientific discovery and revelation is a curious mind. In this issue, Spectrum seeks to comprehend the brain and its various functions.

The brain plays a fundamental role in not only thought and communication, but also in regulating the various physiological processes of the human body. While humanity's understanding of the brain has expanded at unprecedented speed in the past decade, the mechanics and development of the brain, as well as the generation of complex thought and consciousness, remain among the most mysterious and profound realms of science, demanding ever more exploration.

Our features topic, *The Frontiers of Neuroscience and Memory*, explores the complex neurological processes that drive human thought, behavior, and biology. Our writers have detailed the relationship between the Gut-Brain Axis and Autism, Contact Sports and Cognitive Degeneration, and the POMC neuron and metabolism.

In addition to our features topic, this issue of Spectrum also covers recent developments in the fields of Biology, Chemistry, Physics, and Technology. These sections explore a diverse range of topics ranging from the work of 2018 Nobel Prize Winners and novel radio tracers used for the diagnosis of Alzheimer's to the infamously confounding physical phenomenon of Charge-Parity Symmetry violation.

As we embark on our first issue, we would like to thank the writers, editors, and our faculty advisor Mr. Epstein for their patience, diligence, and care for each article and for helping us produce our first issue.

The mind is a powerful tool and an essential topic of exploration. As readers flip through the pages of this issue, we urge them to share in the discoveries, ideas, and findings presented by Spectrum's writers with others and to stay curious in their continual pursuit to further understand the mind, nature, and the universe.

Sincerely,



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NEWFOUND CONNECTIONS BETWEEN THE BRAIN, THE GUT, AND NEUROLOGICAL DISORDERS

In recent research developments, scientific studies have connected the previously unknown causes and treatments for severe neurological disorders with the magnitude and diversity of the bacteria found in the human gut, known as the microbiota.

Research released as recently as 2017 and 2018 has surrounded autism spectrum disorders (ASDs), neurological and psychological disorders that can cause behavioral abnormalities that affect social interactions. The term "autism" was coined by the Swiss psychiatrist, Eugen Bleuler in 1911 to refer to schizophrenia, but has evolved to describe people with social or behavioral issues. Since then, autism has been reclassified as one of many conditions on a spectrum of neurological and social disorders, now known as ASDs. The causes of these disorders are unknown to neuroscientists. After extensive neurological research, Dr. Quinrui Lui, of Peking University, determined that "there are no effective therapies to treat this range of brain developmental disorders." Even with this complex knowledge of its neurological effects, treatments for the symptoms of ASDs severities are not well developed.

In addition to the behavioral impacts of ASDs, impaired gastrointestinal function is directly correlated to the severity of the disorder. Symptoms manifest as nausea, vomiting, diarrhea, and abnormalities in the digestive tract. These symptoms are suspected to cause an increased number of neurons in the prefrontal cortex, an increased brain weight, and atypical neuron patterning, all characteristic of ASDs.

Despite not being aware of the causes and treatments for ASDs, multiple neuroscientists have found links between the severity of ASDs and the composition of the microbiota, the most microbially diverse and abundant region in the human body. Among this newfound knowledge is the discovery of a bidirectional link between the microbiota in the human gut and colon, and the brain. This link occurs through the gut-brain axis in the vagus nerve, a nerve found in the gut and covered in fibers to allow for anti-inflammatory function. Chemical signals released from the microbiota, some of which are neurotransmitters such as serotonin and dopamine, are expressed through the fibers in the vagus nerve. These chemical signals are then able to reach the nervous system by way of the spinal cord, the endocrine (hormone) system, or cytokines which are substances secreted by the immune system. The microbiota can modulate the nervous system the production of neurotransmitters and other metabolizes, as 90% of serotonin is produced in the gut. Changes in the diversity and behavior of the microbiota can minimize the inflammatory stress upon the

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gastrointestinal tract; A low amount of stress upon the gastrointestinal tract can elicit positive changes in mood and social behavior, which can, in turn, affect neurological conditions such as ASDs.

This relationship has proven critical to the partial treatment of patients with various ASDs and other neurological disorders. A recent clinical trial evaluated the impact of a gut bacteria transplant, or Microbiota Transfer Therapy (MTT), on symptoms of ASD-diagnosed children. The therapy consisted of two weeks of oral antibiotics, an intestinal cleanse to prevent misinterpretations of later microbiotic evaluations, as well as an oral or fecal microbiota transplant.

The severity of ASDs symptoms was then tested using the Gastrointestinal Social Responsiveness Scale, known as the GSRS. The GSRS functions by evaluating brain function in different categories, which allows neuroscientists to diagnose autism. Although the GSRS is not typically used as a measure of ASDs severity, researchers have



historically found that higher scores are indicative of more severe symptoms.

Substantial changes in ASDs symptoms were observed throughout the course of the MTT study, as well as an 82% average decrease in GSRS score, 88% of patients experiencing a decrease in their score by at least 50%. Furthermore, patients reported significant recreased magnitude and diversity of the microbiota can lead to anti-inflammatory communication with the gut-brain access. The results of this study favored the notion that patients with less genetic diversity among their microbiota are more prone to severe ASDs and major gastrointestinal issues.

However, other studies revealed in-

⁴⁴Further development of microbiotic treatments and bacterial regulation could create a ground breaking reversal in the current trajectory of the creasing magnitude and severity of ASD, especially among children.⁹⁹

lief in gastrointestinal symptoms of ASDs such as abdominal pain, indigestion, diarrhea, and constipation.

As part of these experiments, microbial genes were extracted and studied to monitor the effects of the microbiota on ASDs. After the administration of the rectal microbiota transplant, a formidable increase in genetic diversity among the microbiota was observed, causing researchers to conclude that inherent negative impacts of increased diversity among the microbiota. An increase of the genus of bacteria Clostridia in the gut microbiota associated with ASDs. Clostridia produces toxins that not only damage and permeate the gut lining, but also influence the nervous system.

Despite the negative impacts of some bacteria, the partial or entire absence of microbiota has also been linked to

BY SAM SINGER

have abhorrent effects on ASDs symptoms. One study explored the impact that lowered microbiota diversity and magnitude has upon the symptoms and presence of neurodevelopmental diseases such as ASDs. The study hypothesized that, because ASDs are associated with lower levels of microbial diversity, changes in the microbiota would be responsible for gastrointestinal, physiology, neurobiology, and behavior. The research examined the social interactions of germ-free mice after the transplant of a lab-created model of ASDs. The quantity and variety of probiotic microbiota within the mice significantly decreased upon the transplant of ASDs. Due to the absence of the protective microbiota, greater levels of stress hormones were produced, especially in the digestive system, causing diarrhea and vomiting. The study went on to explore treatment for ASDs, recommending the use of supplementary probiotics to restore standard levels of microbiota and permit signaling between the microbiota and the brain to decrease digestive stress.

Alterations in the gut microbiome have been observed in people with ASDs, indicating that the microbiota plays a significant role in regulating neurological function and behavior. These new studies shed light upon potential treatments for autism. Further development of microbiotic treatments and bacterial regulation could create a ground-breaking reversal in the current trajectory of the increasing magnitude and severity of ASDs.

The Neuroscience of Trauma-Induced Dreams

S chool could be called a "waking nightmare," but has it ever been a sleeping nightmare? Admit it; you've woken up from a nightmare about those two (or three) stressful freshman-year classes. It's not just you. Nightmares can occur due to traumatic, stressful experiences, and at Horace Mann, academic pressure causes stressful experiences. This rigorous and competitive culture can cause your brain to obsess over your past memories through the process of dreaming.

By Euwan Kim

Dreams are a collection of images, people, and scenes that one has encountered throughout the day. Some oneirologists, neurologists who study dreams, hypothesize that dreams help process emotions, physical details, and events your brain collected throughout the day. Most people dream three to six times a day (about two hours total) but don't remember. The dreams that stay in memory are usually the most intense dreams, occurring during REM phases of sleep.

There are two main phases of sleep: Rapid Eye Movement (REM) and Non-Rapid Eye Movement (NREM). When you first fall asleep, you enter NREM phase. Your brain starts its REM phase approximately 60 minutes after sleep begins, stays in this phase for 10-15 minutes, and returns to NREM before starting the REM cycle again. The most crazy dreams, the dreams where basic law of physics don't work, allowing you to fly, move through walls, or walk

"Horace Mann's ricorous and competitive culture can cause your brain to obsess over your past memories through the process of dreaming."

on water, occur during REM phase. On the other hand, NREM dreams are rational, episodic recountings of your daily memories. Usually, you only remember REM dreams. According to T.A. Nielsen, the recall rate of dreams occurring during REM cycles is 81.8% compared to the 50% rate of those that occur during less intense sleep cycles.

You are more likely to remember REM dreams than NREM dreams because your brain is most active during REM phases. During the REM phase, levels of acetylcholine, a neurotransmitter that sends signals to other parts of your brain and body, are at their highest, meaning that your brain is almost as active as when you're awake. Your heart rate increases, your muscles paralyze, and your brain activity increases, making you more likely to dream. The complete opposite occurs during NREM phases; your heart rate drops, and cognitive brain activity decreases to focus your energy on muscle repair.

Jessica D. Payne and Lynn Nadel believe that memory consolidation influences the difference in recall rates for REM and NREM dreams. There are two systems in which your memory is stored: hippocampal and neocortical. Hippocampal systems store memories that are unique occurences.

Neocortical systems store overlapping occurrences, or anything repetitive happening throughout your day. These two systems work together to store information you'd later find important. First, certain neocortical memo-

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ries gradually fortify details about the things you interacted with that aren't too different from your daily routine. Second, hippocampal memories concerning specific encounters, unique interactions, and backstories behind their occurrence are strengthened. Third, the connection between the hippocampal and neocortical sites are enhanced so that hippocampal memories can be properly recalled with even the most trivial details, even after a long time. Fourth, similar neocortical memories are connected so that even if you can't remember the specific details of each memory, you can feel a similar emotion from the series. Thus, a connection between the hippocampal and neocortical categorizes the multitude of experiences constantly flowing through your brain.

So how does this all play into dreams? Payne and Nadel state that high amounts of cortisol can break the connection between hippocampal and neocortical structures. Cortisol, a stress hormone, plays a significant role in how your brain consolidates memories. An increase in stress causes an increase in cortisol that can cause a small brain spasm. Cortisol also affects hippocampal and neocortical connections. During REM stages, cortisol increases drastically. When there is a lot of cortisol emitted into your brain, it overflows the output field of the hippocampus, disrupting the flow of spatial and temporal context as you are dreaming. Without the hippocampus, the neocortical systems have to rely on disconnected fragments to fill in these memory gaps to continue your dreams. This is what causes dreams that are somewhat related to your past experiences but also bend the space-time continuum.

For example, in a dream you might remember the anxiety you had before one of your history tests but then also be floating through space. The familiar feeling of anxiety comes from disconnected fragments of similarly-linked neocortical memories and the floating through space comes from the memory gaps that the hippocampal systems were supposed to fill in. Additionally, if you're already stressed going to bed, you already have high levels of cortisol pumped into your brain, causing you to have nightmares about your classes. Most traumatic experiences of high schoolers occur in school environments, an effect reflected in teenage nightmares. When your brain is overloaded with stress hormones and the only thing your neocortical system readily has available is a memory of getting your first geometry test back, you're likely to have a nightmare about geometry.

Cortisol is produced during REM phases, when you're more likely to remember your dreams. If you have great memories from your favorite classes, you'll probably dream about them during the NREM phase and not remember them the next morning. Veterans suffer from PTSD dreams, because their PTSD increases cortisol during REM phases, causing violent memory-fueled nightmares.

You are able to control the way you dream. Going to sleep with a calm, positive mindset decreases the amount of cortisol already pumped into your brain. You can always brood about that class when you're awake, but for the few hours you get to sleep every night, you deserve to take a break.

THE CONNECTION BETWEEN CONTACT SPORTS AND COGNITIVE DEGENERATION

KARINA IMAN

very year, sports fans crowd around the TV to catch I the Super Bowl or the next Mayweather vs McGregor, but what we don't hear during the game highlights is the toll these contact sports take on the athletes. Contact sports, specifically football or boxing, can cause cognitive degeneration, a loss of functions in the brain. even with the use of protection like helmets, shoulder pads, or boxing gloves. The most severe brain disease found not only in athletes but also in combat veterans of the US Army, is Chronic Traumatic Encephalopathy (CTE), which is caused by repeated hits to the head over a long period of time. Multiple blows to the head causes proteins to form inside the brain, which kills brain cells. CTE is a silent disease which only begins to show symptoms after it has spread to the brain and affects the victim's behavior by causing aggression or paranoia. Over time, the disease affects worsens and negatively the memory which can eventually progress into dementia. Though all of these symptoms point to CTE, the disease can only be diagnosed after death. CTE is a silent and incurable disease, but scientists know how it

forms in brains, and it starts inside a single neuron. Brains contain billions of neurons which allow us to think and react to everything surrounding us. Neurons have three main parts, the weakest is the axon, which connects the cell body to the axon terminal. Neurons use axons by sending signals down them to other cells. Though the axon is a vital part of the neuron it is also easily damaged since it is very thin and fragile. To send materials and chemicals through a cell, neurons use microtubules which are even thinner and weaker than axons. Since microtubules are so thin, they need support which is where tau proteins come in. Tau proteins are another essential piece in neurons, THE but if a microtubule is destroyed, the tau proteins that stabilize the microtubules can leave its original place and take over the cell and eventually take over different areas of the brain. Clumps of tau proteins move slowly through the brain which is why symptoms of CTE can begin to emerge years after an athlete has started their career or even years after an athlete has finished their career.

1.6 - 3.8 million sports-related concussions occur yearly in the US and football is the main cause of the

reported cases. Throughout a single season of football, a player could undergo thousands of hits to the head and because of this, football players die at a higher rate and a younger age from CTE compared to other athletes of contact sports, like boxing or hockey. This is because of the experience of the most common symptoms in football players with the disease: mood swings, paranoia, and loss of judgment which lead to depression or compulsive thoughts. One study showed that due to the mood swings and loss of judgment, out of five football players with CTE, four died from tragic deaths. The tragic deaths that were caused by the CTE side effects included suicide, dying during a high-speed police chase, and death by accidental gunshot. In the years leading up to the tragic deaths of these football players, they were described as having short-term memory loss and having progressively less and less cognitive function.

Boxers, while dying less due to CTE compared to football players, frequently live longer than other athletes with CTE. They usually were able to live for 30 - 40 years with severe symptoms of the disease. In the same study that showed football players



have a higher chance of a tragic death, it was revealed that the cause of boxers dying less of CTE deaths was also due to the different symptoms of the disease affecting them. Boxers most commonly suffered from memory loss over time, the complete opposite of football players, only showing signs of mood changes at an older age. Boxers also commonly faced a decline in motor skills and experienced Parkinson's-like symptoms such as hand tremors. It was also discovered, that compared to other sports, boxers are also less likely to sustain as many head injuries during matches as they are during training while sparring. Sub-concussive injuries, or injuries which don't cause concussions, happen frequently during sparring, while concussive injuries like knockouts, happen less frequently during matches. Though knockouts seem to be more severe, many small blows to the head like those endured during training for boxers and during matches for football players are more likely to cause CTE. Researchers have yet to find a way to identify CTE in living people, they have identified ways to prevent the disease through rule changes or even awareness. In children below the age of 12, CTE is more likely to form,

decreased risk of head injuries such as flag football instead of tackle football could prevent cognitive degeneration. Rules in Ivy League football were also changed to decrease head injuries. affected, while in football, the The kickoff and touchback lines were judgement center and the mood of moved five yards closer, meaning when players was altered. CTE impacts

so putting children in sports with a the brains of athletes has uncovered new information such as how various contact sports affect the brain differently. In boxing, the memory and motor controls of fighters was

"Clumps of tau proteins move slowly through the brain which is why symptoms of CTE can begin to emerge years after an athlete has started their career or even years after an athlete has finished their career."

players rammed into each other during kickoffs, they wouldn't be running at full speed. Kickoffs were responsible for 20 percent of concussions and after the change, the number of concussions fell dramatically.

In many contact sports, CTE is a prevalent issue which affects athletes' lives outside of the boxing ring or playing field. Though CTE is currently incurable, research on

world-famous athletes and has become a rising issue amongst professional sports and collegiate sports to promote rule changes, which can save minds and lives of young people.

Cryptomnesia

The Psychology Behind

By Brigette Kon

lagiarism is more often than not a conscious decision. When a singer reuses a specific part of another artist's song to in their own work, they actively make this decision and thus must pay in order to gain copyright permission to use it in their own music. When a student copies an academic paper to hand in, they consciously make this decision. Everyone at HM has signed the honor code and understands how important original work is, especially in an academic setting. However, there are times when plagiarism is not intentional. Have you ever told a joke before to a friend, only to find out that you've already told them the joke? Ever gossiped, only to find out that the person you told it to was the one who originally told you that same gossip? These incidents are even more prominent in the entertainment industry. Imagine a musician composes their own music. They write, record, then release their song to the public. A few days later, someone compares it to another song and finds it identical to the song the musician created. The musician will insist that their song is an original, but in actuality that they have indeed heard this identical song before, only they do not recall hearing the original work. What happened to this musician is called Cryptomnesia. These people are victims of a phenomenon where they unintentionally recreate a work they have seen or heard in the past. Interestingly, the work they have inadvertently plagiarized does not have to be another person's; it can be their own work. Most people have experienced Cryptomnesia in some way or another. Cryptomnesia's existence is hard to prove, as a person who claims to experience Cryptomnesia can easily be lying.

There have been some studies proving the legitimacy of Cryptomnesia. The most famous and conclusive study was conducted in 1989, where researchers Alan S. Brown and Dana R. Murphy from the Southern Methodist University conducted three experiments in order to prove the existence of Cryptomnesia. In these three experiments, the subjects in groups would take turns listing off examples of items within a specific category, then they would try to recall which examples they thought of themselves, and finally they would create new examples based off of the original category. Brown and Murphy's first experiment was to test subjects in four-person groups. Their three-step cycle repeated four times, allowing each subject to create four unique examples from one singular

category. After this, they were told to write down their four examples, then generate four more unique ones that hadn't been said by them or any other subject in the group. Any repetition was defined to be Cryptomnesia, as generation of the same response would imply that the subject has forgotten that it had already been said, and thus believes that their response is unique. Brown and Murphy found that, out of the 24 subjects chosen, 17 of them repeated an item already listed when generating new responses, which was 71%

"These people are victims of a phenomenon where they unintentionally recreate a work they have seen or heard in the past."

of total subjects. These subjects plagiarized 33 items total, which was 8.6% of the total responses among all subjects. The subjects plagiarized during both the generation of their original four items and the recalling of everyone else's items. This experiment concluded that unconscious plagiarism very much exists, and it occurs across a variety of tasks, contexts, materials, and conditions under which responses are generated.

The most famous cases of Cryptomnesia are the cases of Helen Keller and George Harrison. Helen Keller was an author and political activist who was also deaf and blind. When she was eleven years old, she wrote a story called The Frost King. Her story was published in her school's magazine and later in a journal. Readers of this journal discovered that The Frost King was nearly identical to another story The Frost Fairies by Margaret Canby. Keller denied any recollection of The Frost Fairies and claimed to never have read it before, but it was soon revealed that a few years prior to writing The Frost King, someone had read the story to Keller. She was acquitted of deliberate plagiarism when the majority of the jury voted "not guilty" and determined this incident to be a case of Cryptomnesia.

Former Beatles member George Harrison was not so lucky. Harrison composed "My Sweet Lord" in 1971. It was a hit. Then, a few weeks after its release, Bright Tunes Music filed a copyright infringement suit. Bright Tunes owned copyrights to the song "He's So Fine," which had the same exact melody as Harrison's "My Sweet Lord". "He's So Fine" topped the radio charts in 1963, meaning that Harrison couldn't deny the likelihood

Harrison were unconsciously plagiarizing works, how do we know that they are telling the truth? How can we differentiate between those who claim to have experienced Cryptomnesia and those who are lying in order to lessen their crime? Cryptomnesia, while everyone has experienced it at least once in their life, is extremely rare. Keller and Harrison created works nearly identical to the original, a feat only likely in cases of Cryptomnesia. Perhaps the court ruled both Keller and Harrison victims of Cryptomnesia because they truly had nothing to gain from plagiarizing the original works when considering the consequences of being exposed. Determining whether someone experienced Cryptomnesia is subjective, which muances plagiarism in academic disciplines. For example, consider a brilliant thesis by a student, which happens to be identical to a thesis in a famous essay the teacher knows. Any teacher would conclude that the student plagiarized and copied the idea from the essay, but what if the student read this essay a long time ago and thus only subconsciously remembered the thesis? Vice versa, what if the student genuinely copied the thesis and is only claiming to be a victim of Cryptomnesia for their own benefit? Can the teacher really definitively know the truth without there being some gray area? For now, researchers will continue to study exactly how Cryptomnesia occurs and ways to identify and prevent Cryptomnesia.

that he listened to the song many times. In

fact, Harrison agreed himself that the songs

were extremely similar. Harrison attempted

to settle out of court, but Bright Music insisted his giving up of copyrights to his

song. The case went to court in 1976, and

Harrison was found guilty of subconscious plagiarism, the court ultimately coming

to conclusion because Harrison admitted

to hearing "He's So Fine." Harrison paid

While the court ruled that both Keller and

\$1,599,987 to Bright Tunes as a result.

TO LEARN MORE ABOUT CRYPTOMNESIA, READ THE RIVER OF CONIOUSNESS, BY OLIVER SACKS Elucidating the Role of the POMC Neuron in Glucose Sensing

Rosy Aurora

ndocrinology is an exciting field of medicine that has evolved from a discipline focused primarily on the effects of hormones traveling "extracellularly" to one that now studies the connection between genetics, gene expression, and the various signals our cells send to organ systems to regulate our metabolism. Consequently, there is a new body of scientific research dedicated to the study of cellular systems like Hypothalamic Proopiomelanocortin, POMC neurons, specialized cells that transmit information through electrical and chemical signals to the brain to influence the metabolism and drive appetite suppression. Understanding the nature of these cells, how they interact with other cells and the hypothalamus could lead to novel treatments for diabetes, obesity, and metabolic syndrome.

DRP1 suppresses Leptin and Glucose Sensing of POMC Neurons, led by Yale Medical School professor Sabrina Diano, investigated the intracellular mechanisms that enable POMC neurons to respond to signals from nutrients such as glucose and concluded that the ability to control blood sugar levels is influenced by "mitochondria-shaping processes" that activate the neurons responsible for sending signals to the hypothalamus to drive this process. The importance of the Yale study lies in its demonstration of the "role of the dynamin-related protein, DRP1 — which controls mitochondrial fission, or the splitting of mitochondria — in the regulation of glucose and energy homeostasis," said Anna Santoro, a postdoctoral associate and the first author on the study.

The hypothalamus, located in the brain, connects the endocrine system to the central nervous system. Responsible for regulating the body's glucose homeostasis and energy, metabolism, and weight, the hypothalamus inhibits feeding behavior through POMC neurons from the nervous system by responding to peripheral signals, including nutrients and sending a series of signals to the hypothalamus.

A previous study by Diano, published in 2011 in the magazine Nature, identified reactive oxygen species, (ROS), as important regulators of POMC neurons. During the oxidation of glucose and fatty acids, a significant amount of ROS is produced by mitochondria within the neurons. The Yale study expanded on this research and looked at how the changes in size and function of mitochondria in POMC neurons affected energy and glucose regulation. The researchers focused on DRP1 protein because it is known to induce fission in mitochondria. Two test groups of mice were established one in which DRP1 was deleted during development and one in which the protein was deleted in adult POMC neurons.

In the first group, the deletion of DRP1 protein led to a reduction in the number of POMC neurons,



Microscopy

Flourescent staining of arcurate nucelus in the hypotalamus shows POMC Neurons (green)

which eventually led to obesity and Type 2 diabetes in the mice. The findings suggested that DRP1 is critical to the development of POMC neurons and metabolic regulation. The second group of mice, in which DRP1 was deleted temporally in mature POMC cells, did not become obese or develop diabetes and instead showed improved glucose metabolisms. In addition, the researchers discovered that the mitochondria of activated hypothalamic glucose-sensing POMC neurons are bigger than those observed in silent POMC neurons and DRP1 protein, which induces mitochondrial fission. The researchers concluded that "DRP1 lowers the ability of POMC neurons to regulate blood glucose levels, as DRP1-mediated mitochondrial fission may function as a mechanism to silence the glucose-sensing neurons." In mature POMC neurons, the deletion of DRP1 led to increased responsiveness to changes in glucose levels and improved glucose metabolism. The researchers also looked at DRP1 presence

and mitochondrial size in POMC neurons when mice populations had eaten and fasted. Fed mice had lower levels of DRP1 and increased mitochondria size, "suggesting that mitochondrial fusion the opposite of fission — may be required to activate POMC neurons".

The discoveries from the Yale study provide insight into potential diabetes treatments. For example, DRP1 could be targeted in the future to treat Type 2 diabetes patients and improve their responsiveness to hypoglycemia, or low blood sugar, a complication of Type 1 diabetes treatments like insulin injections. Additionally, further research in the hypothalamic regulation of the metabolism via POMC neurons may pave the way to novel treatments for diabetes, metabolic syndrome, and obesity. With metabolic disorders on the rise, it is imperative to further understand the underlying biological mechanisms of their pathogenesis.

"FURTHER RESEARCH IN THE HYPOTHALAMIC REGULATION OF THE METABOLISM VIA THE POMC NEURON MAY PAVE THE WAY TO NOVEL TREATMENTS FOR DIABETES, METABOLIC SYNDROME AND OBESITTY."

"WITH METABOLIC DISORDERS ON THE RISE, IT IS IMPERATIVE TO FURTHER UNDERSTAND THE UNDERLYING BIOLOGICAL MECHANISMS OF THEIR PATHOGENESIS."





NOBEL PRIZE IN PHYSIOLOGY OR MEDICINE

AWARDED TO DR. JAMES P. ALLISON AND DR. TASUKU HONJO

COVERED BY MARINA KAZARIAN



Monday, October 1, 2019, James P. Allison and Tasuku Honjo received the Nobel Prize in Physiology or Medicine for their discovery of a new method of immunotherapy, where the body's immune system is manipulated to attack cancer, the uncontrolled growth of abnormal cells. Their work has resulted in a new class of drugs and hope for patients battling the disease. Dr. James P. Allison is the Chairman of Immunology at the University of Texas M.D. Anderson Cancer Center and has worked at the University of California at Berkeley and Memorial Sloan Kettering Cancer Center. Dr. Tasuku Honjo is a professor at the Department of Immunology and Genomic Medicine at Kyoto University in Japan and previously researched at Osaka University, the University of Tokyo, and the National Institutes of Health in Washington, DC.

The two immunologists found a brand-new way to use immunotherapy.

Before the discoveries, many scientists had experimented with the idea of immunotherapy in addition to surgery, radiation, chemotherapy, and hormonal treatments. This discovery in the field of immunotherapy, however, is an innovative treatment that shows a newfound promise that scientists have not yet been able to discover.

Allison and Honjo's work revolved around T-cells, a type of white blood cell that fights off diseases. However, T-cells cannot kill off every single malignant cell; T-cells carry checkpoint molecules that prevent them from killing off cells when necessary but also let cancer cells lock onto them, blocking the T-cells from killing the malignant cells. The T-cells use a balance of these inhibitors in order to fight off diseases without destroying healthy cells. In the 1990s, Allison and Honjo, working independently, suspected that suppressing these proteins that limit the ability of T-cells to fight off cancer cells could allow the immune system to start attacking cancer more efficiently.

Dr. Allison discovered the CTLA-4 checkpoint molecule and Dr. Honjo found the protein PD-1. Based on the discovery of these molecules, drugs called checkpoint inhibitors were created. The first few approved checkpoint inhibitors include Ipilimumab (which is also called Yervoy), Nivolumab (Opdivo), and Pembrolizumab (Keytruda). Ipilimumab was created based on Dr. Allison's work, whereas the later drugs stemmed from Honjo's research. More of these drugs are currently in development. These checkpoint inhibitors stop the checkpoint molecules from impeding the ability of the T-cells to fight harmful cancer cells, allowing the T-cells to do the job of attacking cancerous cells.

PD-1, like CTLA-4, functions as a checkpoint; however, the two molecules have different mechanisms. While

experimenting with PD-1, Honjo found that patients with metastatic cancer had long-term remission and could possibly be cured. In 2010, Allison found that manipulating CTLA-4 caused the conditions of people with advanced melanoma, a cancer of skin pigment cells, to greatly improve. Any remaining cancerous cells ended up disappearing in most of the patients. Yervoy extended the survival of patients with late-stage melanoma: 20% of those treated live for at least three years and many of those patients live for over ten years. Sharon Belvin, a woman who was on the verge of dying from melanoma, was cured by four doses of Dr. Allison's drug. Belvin now has two children and runs half marathons. This success was unprecedented and it further shows the utility of immunotherapy for patients who have run out of options. Clinical trials are testing the efficiency of the treatment for other types of cancer.

Despite the numerous benefits of this new treatment, there are several downsides and side effects. The treatment does not help every patient. It is limited to only some types of cancers, including lymphoma, lung, kidney, bladder, head, neck, and skin cancers. Costing more than \$100,000 per year, the treatment is not easily affordable. There are also several side effects due to the fact that the immune system could ruin healthy tissue. The T-cells, no longer having

a balance of checkpoints and accelerators, could end up attacking healthy cells in the body. This imbalance could result in the inflammation of the lungs, intestines, or heart. It could also cause the thyroid to become sluggish, damaging the pancreas and potentially resulting in diabetes and the development of rheumatoid arthritis, a joint inflammation disease. When the treatments were first put on the market, there were some cases where the drug caused death in the patients. Ipilimumab (Yervoy) is considered to have the worst side effects of all of the checkpoint inhibitors. Over the years, doctors have attempted to control the side effects of the drugs. By lowering the cost of the treatments both the treatments and the idea of immunotherapy could gain popularity and become one of the main treatment options for cancer.

It has been shown that manipulating both CTLA-4 and PD-1 is more effective, especially in patients with melanoma. This form of immunotherapy is gaining popularity; there are now many new checkpoint therapy trials and different proteins to target. Immunotherapy has recently become a vital tool in treating diseases such as cancer. Scientists have begun to delve deeper into this type of therapy, impacting cancer treatment in the near future. "This discovery in the field of immunotherapy is an innovative treatment that shows a newfound promise that scientists had not yet been able to discover."



The Role of p53 in Cancer Stem Cells

p53 is very important in understanding and potentially preventing cancer, and it is one of the only tumor suppressor genes to be formally evaluated as a viable form of cancer treatment.

re we capable of creating a vaccine for cancer? p53 may be the answer. Cancer refers to a multitude of diseases L in which some of the cells in the patient's body begin to divide without stopping, causing the formation of tumors. As we go through life and our cells divide, we accumulate mutations in our DNA. Individually, these mutations may not necessarily be harmful, but it is the accumulation of them that can develop cancer. However, the cell cycle has many checkpoints that monitor for mutations, allowing the cell to catch potentially dangerous mutations early. When these checkpoints begin to fail, mutations can accumulate more easily, leading to a higher risk of cancer. p53 is a tumor suppressor, meaning that it helps a checkpoint regulate the cell cycle by causing cell arrest, senescence, or apoptosis. Cell arrest is when the cell cycle is stopped so that the cell has enough time to repair DNA damage, and apoptosis is when the cell enters G0 phase, or programmed cell death. The checkpoint that p53 interacts with is G1, right before the cell enters synthesis where DNA is replicated.

TP53 gene codes for the p53 tumor suppressor. Normally, there are low levels of p53 because it is unstable and degradeds easily because it is tagged by Mdm2, which acts as a ubiquitin ligase. Acting as a ubiquitin ligase means that Mdm2 tags p53 with ubiquitin, marking it for proteasomes to break it down. Only when DNA is damaged do p53 levels rise.

How does p53 suppress tumors? p53 stimulates the transcription of genes such as p21 by binding to the regulatory region of p21 which codes for the protein p21. p21 is a Cdk

inhibitor protein which prevents the activation of G1/S-Cdk complexes. p53, by preventing the activation of G1/S-Cdk complexes, stops the cell from entering the S phase (where DNA is replicated) at the G1 checkpoint. Since p53 is activated when there is DNA damage, it suppresses tumors by preventing the cells with damaged DNA to proliferate.

Another way p53 suppresses tumors is by inducing apoptosis. One way is by interacting with certain tumor necrosis factor receptors, and by forming death-inducing-signaling-complex (DISC), leading to the activation of caspases. The activation of certain caspases cleaves effector caspases, directly causing apoptosis. p53 also induces the expression of PUMA, Bax, and Noxa. PUMA codes for 2 proteins, PUMA- α and PUMA- β which induce apoptosis. However, PUMA and p21 operate in a balance: if p21 is disrupted, the cell undergoes apoptosis, and if PUMA is disrupted, the cell undergoes cell arrest.

In embryonic stem cells, p53 regulates the suppression of self-renewal and the differentiation of the cells after DNA damage. It does this by binding to and suppressing the promoter of transcription factors and pluripotency factors. For example, the suppression of the Nanog and Oct4 genes in mice forces the cells to differentiate into cell types in which p53 can induce cell arrest and apoptosis. The Oct4 gene also causes the activation of p53 by reducing the expression of Sirt1 (an enzyme that suppresses p53). Additionally, p53 activates the expression of miR-34a and MiR-145 that suppress stem cell factors, ensuring that the cell does not regress into pluripotency.



Induced pluripotent stem cells (iPSCs) come from terminally differentiated cells that can differentiate like embryonic stem cells. When there is a lack of or reduced levels of p53, there is a greater presence of iPSCs. Simultaneously, this lack of p53 decreases cell arrest and apoptosis, causing an increase in the pluripotent cells. It was also found that cells without p53 could still be reprogrammed, forming iPSCs often with mistakes in the DNA. This suggests that p53 not only controls the amount of iPSCs but also the quality. Naturally, the more genetic deviations present, the more likely it is that cancer will develop.

In mesenchymal stem cells (MSCs), p53 plays an important role in regulating proliferation and quality. This is important, as evidence suggests that MSCs that acquire mutations in genes (such as p53) may function as tumor initiating cells (TICs). These MSCs may be capable of inducing the development of sarcomas, a kind of highly malignant tumor. Additionally, the transformation of MSCs is dependent upon changes in the p21/p53 pathway. Once p53 genes have accumulated enough mutations, they are able to increase the rate at which cells become iPSCs. At that moment, the barrier between dedifferentiation and the formation of cancer stem cells is gone. Dedifferentiation is the regression of already differentiated cells back into a simpler state similar to stem cells.

p53 is very important in understanding and potentially preventing cancer, and it is one of the only tumor suppressor genes to be formally

evaluated as a viable form of cancer treatment. At least half of cancer patients have a mutated p53 gene, resulting in altered levels of this protective tumor suppressor. If a mutated p53 gene can be detected early on, we can recognize cancer before it becomes symptomatic. Although p53 shows great potential, its delivery and integration is still under study. Results from a recent study in February, 2018 showed that a vaccine for cancer may be possible by introducing the immune system to iPSCs that resemble tumor cells, but are unable to replicate. In doing so, the researchers safely exposed the immune system to cancer-specific targets. Although more research around the role of p53 in cancer stem cells is required, modification of p53 levels seems to be a very promising method of cancer treatment.

The image depicts two

expressing p53 genes

with a loss-of-function

Cancer Stem Cells

mutation.

FALL 2018



latimes.com

Deep Sea Density Lakes

by Jayer Yang

The ocean is one of the Earth's greatest mysteries. It takes up 71% of the Earth's surface, yet we still have so much to learn about its deep blue depths. An interesting feature of the ocean's diverse landscape is the seafloor's underwater lakes. These deep sea Density Lakes, or brine pools, are indents in the sea floor filled with super-dense, super-salty water, only habitable to the most resilient of organisms.

Density Lakes are common in the Red Sea and the Gulf of Mexico, a lake recently discovered in the latter dubbed the "Hot Tub of Despair," notorious for killing almost anything that attempts to venture into its salty depths. Sitting around 3300 feet below the water's surface, the pool has a circumference of about 100 feet, and was first discovered through the use of a remotely controlled submarine.

Deep sea lakes are formed over millions of years as a result of salt tectonics. Following the Jurassic era, the Gulf of Mexico, which dried up and left nothing behind but an

incredibly thick layer of salt (roughly five miles thick), opened back up to the sea, and flooded with water. Eventually, the sediment that built up onto the salt layer became heavy enough that the salt layer shifted and deformed, causing the floor to give way and form a crater in the seabed. The seawater then flooded in and hit the salt, causing the salt layers to dissolved into the water around them. This raised the water's salinity, or salt concentration, resulting in an increase in density. The immense salinity and density of the water in the pool rendered it essentially impossible to mix with the surrounding, unsaturated water, causing the salty water to settle into the crater and form an underwater lake. Over time, minerals amassed around the crater, creating a lip that rises around three meters above the ocean floor.

The pools formed are not dissimilar to the rivers and lakes encountered on land, sharing a few distinct characteristics. A clear lake surface is formed where the dense salt water meets the seawater and does not mix. There are distinct shorelines, called haloclines, that are present where the seafloor began to collapse. As a result of the high salt concentration, fish can also float on top of brine pools similarly to how people can float on the Dead Sea.

While these lakes may look pretty, it is important to remember that the lake water is lethally salty, having about five times

"Interestingly, as a result of the high salt concentration, fish can also float on top of brine pools similarly to how people can float on the Dead Sea."

the concentration of salt as the rest of the ocean. The salt water also contains almost no oxygen and dangerously high amounts of methane and hydrogen sulphide. When paired with the water's incredible salinity, the water becomes highly toxic. This prevents the water from mixing with its



"The depth below the ocean's surface at which these basins are located doesn't allow much or any sunlight to reach those creatures, meaning the key to the organism's survival lies with its ability to produce food for itself in the almost total absence of sunlight."

surrounding water and also makes it very difficult for any life to thrive inside of or around the lake.

Yet, life finds a way. There are a few creatures that live in and around these habitats, thriving in the relatively warm temperatures. In addition to this, the toxicity of the deep sea lake makes it an ideal, albeit risky destination for organisms hoping to scavenge the remains of anything recently deceased. Those organisms have to survive without a constant light source in the extremely salty depths of the brine pool, meaning that the organisms that thrive in this setting are mostly extremophiles. The depth below the ocean's surface at which these basins are located doesn't allow much or any sunlight to reach those creatures, meaning the key to the organism's survival lies with its ability to produce food for itself in the almost total absence of sunlight. The organisms have to rely on chemosynthesis, the synthesis of organic compounds through inorganic chemical reactions, to sustain themselves.

A primary example of life like this would be the densely packed, reef-like arrangement of mussels that line the edge of the depression. These organisms have the capability to obtain chemical energy from bacteria that can produce nutrients from the methane and other chemicals in the pools. Other life such as symbiotic bacteria or tube worms can also exist in those conditions, but for larger organisms like crabs or urchins, the intense concentrations of chemicals and the hypersalinity would prove fatal, killing them and pickling them on contact, preserving them in salt.

Such is the extent of the biological resilience exhibited by some of the bacteria in the brine that scientists are using these organisms as a basis for finding extraterrestrial life. Recently, scientists have hypothesized that life could exist on the red planet. Conditions on Mars allow for the intermittent existence of small brine pools. The criteria for surviving in a brine on Mars are not dissimilar to those of surviving in a brine on Earth. The organisms must be oxygen-independent to survive the minuscule concentration of dissolved oxygen. At the same time, Mars may produce oxygen-rich brines, particularly at its poles. Research is currently underway to determine if life in Mars' brine pools is possible.

Though extremely toxic, Earth's very own deep sea density lakes have a sense of beauty to them. The salt water spills over the mineral dams on the edge of the crater, creating what look like underwater waterfalls. The lakes sport vibrant mineral deposits and intricate crystal formations that cause the pool to stand apart from the muddiness of the surrounding water, leading to a colorful, yet deadly, addition to the ocean floor that nobody would expect.



2018 Chemistry Nobel Prize: Enzyme Evolution and Phage Display Technique

Awarded to George Smith, Frances Arnold, and Greg Winter

Covered by Ryan Rosenthal



n October 3rd of 2018, Frances H. Arnold became the fifth woman to ever receive a Nobel Prize in chemistry, for her revolutionary work in the directed evolution of enzymes. Directed evolution means to guide an organism, a part of an organism, or a group of organisms to a specific evolutionary goal, through the use of naturally occurring mutations. In order to fully grasp the gravity of her discoveries, one must first understand what her and her research team set out to accomplish. Arnold attempted to use directed evolution to create more efficient proteins, and to form new and useful enzymes for pharmaceuticals and medicines. This can be achieved through altering the environment in which the subject exists. Directed evolution is not a new idea. In fact, for decades, scientists have been successfully directing the evolution of other macromolecules, such as DNA and RNA. Proteins present a whole other level of difficulty, however, because of their more complex development. While DNA is formed through the ordering of base pairs into longer sequences, proteins

requires the extra step of folding. Protein folding is a process that scientists do not yet fully understand, and thus presented the seemingly necessary step of learning more about it.

With the barrier of understanding an extremely complex process ahead, Arnold had her work cut out for her. Arnold set out not to understand the protein formation process, but to find a way around the need to understand it. It wasn't until after years of research that her aspirations began to come to fruition. In 1993, Arnold published paper detailing her first concrete а achievements in directed evolution. By 2009, she finally had a clear-cut, reliable, and efficient method of directing the evolution of enzymes. Despite being extremely complex and temperamental, evolution has no issues altering and adapting proteins to new situations. Her process circumvented the apparent need to understand proteins as a whole, and instead utilized what natural evolution was capable of doing. Directed evolution gets around the need to chemically and painstakingly alter protein structure, and instead controls and directs already existing mutations of the protein making process to create new and more efficient proteins. There are hundreds of different recombination processes and mutations that a protein can go through, and directed evolution selects which ones the protein will undergo. By applying this process to homologous proteins, the resulting proteins can exhibit traits outside the range of possibility for the parent proteins. What this means is one can create a protein whose use in no way relates to that of the protein used to create it. For decades, humans have been using naturally occurring proteins in food, pharmaceuticals, and other consumer goods, but have never been able to idealize or alter said proteins, until now.

In 1970, John Maynard Smith wrote a paper describing proteins as elements of a nearly endless plain, which he called the Protein Fitness Landscape, maintaining that only a microscopic fraction of the possible proteins are used by organisms. The landscape has had many interpretations and iterations, but all depict many peaks and troughs, with more fit (useful) proteins

Directed evolution has taught scientists many things about proteins and evolution as a whole.

higher up in the peaks. Only proteins that are biologically useful are made, and as a result, there is an endless sum of untapped resources contained within the unused proteins. Directed evolution is a way to access these previously inaccessible resources.

The goal of directed evolution is to guide proteins through mutations as they move higher and higher up on the Fitness Landscape. Directed evolution eliminates the majority of proteins that can possibly be made, so the search for a useful one can be narrowed significantly. The process takes base proteins that are proven to be useful in nature, and evolves them until the are useful in a different way. The process that Arnold developed consists of three main steps: subject selection, mutation, and library formation. The first step is when the scientists select which base protein they will use. The more uses a base protein naturally has, the more useful proteins it can most likely create. The protein is placed inside of hundreds of environments. Next, the scientists alter the conditions in which the protein is held, in order to

cause it to mutate in select ways. Instead of directly altering the protein, Arnold deemed that it would be easier and more effective to allow the protein to evolve naturally, despite being under highly controlled conditions. The final step is to identify which of the resulting proteins are viable and useful. In the 1980s, Arnold's partners, George P. Smith and Sir Gregory P. Winter, developed a system called phage display, in which proteins are analyzed using bacteriophages. A bacteriophage is a virus that infects a bacteria, and multiplies within said bacteria. These phages release proteins that react with and highlight mutations within the bacteria. Using this tool, scientists can screen their proteins for useful adaptations. Those which are not useful are discarded, while useful ones are set aside. Generally, the most effective resulting proteins will have only one mutation, because most screening methods can only determine the use of a protein after on mutation. This process is then repeated for each of the resulting proteins, until no more useful proteins can be formed, and an optimal protein has been created. Directed evolution, as well as natural evolution, have the same goal, which is to create optimal responses to changing situations. Directed evolution is simply trying to lead the process in ways that best serve human society today.

Directed evolution has taught scientists many things about proteins and evolution as a whole. For one, it has expanded our knowledge of the limits and the capabilities of human intervention in nature. In addition, it has brought to light the importance of stability in adaptation and evolution. Directed evolution is a relatively difficult concept to grasp. One metaphor that makes the process easier to understand uses the Protein Fitness Landscape as a basis. Imagine you are going on a hike in the protein fitness landscape. The goal is to get as high as possible, but there are many paths to get there. Most of the paths end in dead ends, but a select few allow you to get all the way to the highest peak. This is exactly what directed evolution is. The process is lengthy and time consuming, but the end result is well worth it.



Newly Discovered Circular Flourescent Dyes



Demonstrate Practical Applications

Elias Romero

HORACE MANN SPECTRUM



The following figure illustrates the chemical structure of the circular dye

n September 18, 2018, Chemists from the University of Oregon made an astounding discovery. They created a new type of circular, water soluble, fluorescent dye that emits colors based only on the diameter of nanohoops.

Nanohoops are the small, circular rings of carbon that make up a nanotube. Nanotubes are microscopic, cylindrical structures of carbon and hydrogen atoms. A dye is a colored substance used as a pH indicator and a stain. Fluorescence is the ability to absorb and re-emit light. Fluorescent dyes are molecules with both abilities. They can absorb and release light at a longer wavelength and function as pH indicators. The University of Oregon dyes are fluorescent dyes made out of nanohoops.

What makes these circular fluorescent dyes different from other substances? Other substances, like Green Fluorescent Protein (GFP), emit certain colors in response to the input light. The circular fluorescent dyes emit their colors as a function of nanohoop diameter. While other nanohoop structures are not water soluble, these circular fluorescent dyes are. This opens up potential applications in biology and technology.

The novel structural and chemical properties of circular fluorescent dyes have advantages over existing tools. Fluorophores, flat-structured fluorescent compounds, label molecules in research and diagnosis. Their fluorescent photons react with the molecule's photons to emit a spectrum of colors unique to the labeled molecule. Unlike fluorophores, circular fluorescent dyes are non-planar and have water soluble chemical side-chains. These side-chains allow intercellular transport across cell membranes. This property is necessary for treatments and detailed observations of cell biology beyond what flat fluorophores provide. Circular fluorescent dyes also maintain fluorescence in acids and bases. This allows functionality in extreme environments.

Beyond medical applications, there are many everyday applications of fluorescent dyes. Fluorescent dyes are part of lighting applications including fluorescent tubes and glow sticks. Light Emitting Diodes (LEDs) use fluorescent substances. The structure of the substances determine the color of light emitted. Fluorescent bulbs are both safer and more efficient than incandescent and halogen bulbs. They give off more light and less heat, increasing brightness, efficiency, and lifetime. For these reasons, compact fluorescent lighting is useful in large spaces that need lots of light, like greenhouses. The reduced heat also means that fluorescent bulbs are less likely to cause a fire. The drawback to fluorescent bulbs come from the toxicity of fluorescent substances. Because of this, breaking a bulb is dangerous, requiring care during handling, transport, and disposal.

Scientists have only scratched the surface of what these circular fluorescent dyes can do. The new circular fluorescent dyes are under investigation for use in biological imaging. After more experimentation, the scientific community will uncover new biological and technological applications of these dyes. "Scientists have created a new type of fluorescent dye that functions in water and emits colors based only on the characteristics of their circular nanotubes."

Novel Radio Tracers Alzheimer's Disease with Positron Emission Tomography

The prevalence of Alzheimer's Disease in people age 65 and older has increased exponentially over the past two decades and is now the sixth most common cause of death in the United States. Projected numbers show that the cases of Alzheimer's will only continue to increase; there are already 5.7 million Americans affected by the condition. As these statistics have grown and will continue to rise, the demand for research and a cure is becoming increasingly necessary.

Most people affected by Alzheimer's are 65 or older, while others experience early-onset Alzheimer's Disease starting at the age of 40 or 50. The symptoms of Alzheimer's typically include short term memory loss and confusion as well as behavioral changes such as trouble speaking, eating, or swallowing. It can be difficult to predict whether someone will be diagnosed with Alzheimer's, but scientists are looking for a way to diagnose patients before the condition fully manifests. As the disease develops, several changes occur in the brain, therefore preventing it from functioning correctly. Symptoms continue to worsen over time and can affect a person's chance of survival. As of right now, there is no cure for the disease, but being able to identify it in its early stages can be beneficial.

Research has shown that two structures, plaques and tangles, form in the brains of Alzheimer's patient. Plaques are built up between nerve cells in the form of beta-amyloid, and tangles are formed with tau, a protein that collects in brain cells. Beta-amyloid and tau are both proteins that play a role in neuronal transmission. Patients with Alzheimers have a buildup of these two proteins, leading to interference along the neuron. Recently, new radiotracers have been developed to identify the growth of tau in the brain through PET (Positron Emission Tomography). A radiotracer is a radioactive substance that is inserted into the bloodstream to track chemical changes in the tissue.

The tau protein plays an important role in the brain, as it stabilizes microtubules, which form as part of the cytoskeleton, and helps with the transport of neurons across axons, the nerve fibers which transmit signals. There must be a certain amount of the protein to provide a

KRISTIN YUNG

balanced environment because either a surplus or a lack of tau could lead to issues for the function of neurons. Normal tau levels have 2-3 phosphate Alzheimer's groups; in patients, aggregated tau contains 5-9 moles of phosphate. Tau tends to localize at the axons of neurons, and tangles that form would hinder transport along the neuron. It has been observed that polyanions can encourage tau aggregation, or buildup, that resembles fibers in those diagnosed with Alzheimer's. Researchers have found that phosphorylation, the addition of a phosphate, is a sign of aggregation, meaning that it could be a warning sign for people developing the condition.



Alzhiemer's Brain



Normal Brain

Due to the increase in knowledge about the tau protein, there is a stronger potential for radiotracers to determine tau aggregation in brains.

The scan would provide key information in the process of diagnosing a patient with Alzheimer's. It plays a significant role in early and accurate diagnoses, which is something that is sought after by researchers and doctors. Tau plays a crucial role in the function of the brain but altered levels of it can easily deter the brain's normal functions. Having these novel radiotracers would allow doctors to discover the disease during its earliest stages, which could be useful in preventing severe cases.

The radiotracers are capable of creating an image of the tau aggregates of a brain by utilizing Positron Emission Tomography. Positron Emission Tomography is a radiology procedure used to look at tissues in neurology, oncology, and cardiology. A radionuclide (radiotracer), a small radioactive substance, is used during the procedure to determine the ability of an organ or tissue to metabolize. It also analyzes the properties of the organ or tissue and looks for biochemical changes that could relate to a disease. A scanning device identifies subatomic particles from the radiation of the radionuclide after it is distributed to the organ or tissue. This process is used to identify tau aggregation in brains of patients to aid the diagnosis of Alzheimer's. With these radiotracers, researchers have much more potential to analyze the causes and effects in Alzheimer's.

These developments in Alzheimer's research are key to analyzing the changes that a brain undergoes when developing the disease. There are many unknowns when it comes to brain structure and development; the novel radiotracers can now identify tau aggregates, and with more research, similar technology could be used to detect other structures in the brain. This is an important step in promoting early diagnosis of Alzheimer's, thus increasing the likelihood of preventing the condition from worsening in many cases.

Parkinson's and Schizophrenia are other examples of diseases involving brain abnormalities, and research/diagnoses for these conditions would benefit from processes like Positron Emission Tomography. With slight adjustments, it could be used to identify many other brain conditions as well.

Although diagnosing and treating Alzheimer's is very complex, these radiotracers are an important step towards gaining more knowledge about the disease. Being able to identify the causes of the disease and how the brain changes during its development is vital for finding effective treatment. As knowledge continues to grow about Alzheimer's, new technologies will continue paving the way for new research and revolutionary discoveries.

PET SCAN:

Using an amyloid biomarker as shown in white, PET scans highlight the physiological differences between the brain of an Alzheimer's patient compared to that of a normal patient.

"The radiotracers are capable of creating an image of the tau aggregates of a brain by utilizing Positron Emission Tomography"

Carbon Nanotubes and Their Applications

Catherine Mignone

as it ever crossed your mind that you could possibly travel to space L by elevator? Carbon nanotubes are the source of this phenomenon and can be used to create amazing technologies, from the proposed "elevator to space" to delivering tiny medicines into the human body. These miraculous tools are nanofibers which are flexible, extendable, one billionth of a meter wide chains of carbon, and have a wide range of uses. There are four fundamental forces of nature: Electromagnetism, Weak Interaction, Strong Interaction, and Gravitation. However, in the nano-level, mass does not have a role, so scientists and researchers have had to create many new techniques and technology.

strongest materials known, as well as the stiffest. They can also absorb energy from any wavelength, and therefore be used for nextgeneration solar panels. They are always either electric or semi-conductive, so they can be used in many electrical circuits and systems. Despite all of the insane technology carbon nanotubes have to offer, the most interesting and life-changing applications lie in their medical and pharmaceutical applications.

Before carbon nanotubes can be put to use, they must be created. In their raw form, they are hydrophobic, or water repelling, but researchers have made modifications to their raw forms by adding polyethylene glycol, a hydrophilic polymer to the nanotube



Nanotechnology is everywhere: in electronics, in communication, and in heavy industry and is used to complete circuits, power your phone, and filter air into commercial airplanes.

Carbon nanotubes are made out of graphene, an allotrope of carbon. Graphene, charcoal, and diamonds are all allotropes of carbon, however, carbon nanotubes are much different than the other allotropes of carbon because they have completely different properties. In terms of tensile strength and elastic modulus, carbon nanotubes are the structure. A group of scientists specializing in nanotechnology and microbiology, Liu, Tabakman, Welsher, and Dai experimented with adding polyethylene glycol so they can be used in vivo and in vitro. In vivo means inside of a patient's body, and in vitro means outside of the patient. A test tube or culture dish is an example of in vitro. The process of making the nanotube hydrophilic is called PEGalation. Another practice used to make carbon nanotubes usable is the cycloaddition reaction, a chemical reaction that covalently "A POTEN-TIAL USE OF CARBON NANO-TUBES IS BUILDING AN ELEVATOR TO SPACE."



bonds the carbon nanotube with a hydrophilic substance or chemical. All of these processes and reactions, however, damage some properties of carbon nanotubes, however, they are still capable of doing incredible things.

Carbon nanotubes are used in both in vivo and in vitro procedures. Once wwcarbon nanotubes are created and ready for use, they have a wide spread of potential applications. For in vivo applications, researchers have recently found that carbon nanotubes can enter the body without any toxic backlash, and are excited about using them for cancer treatments. Carbon nanotubes are photoluminescent, so that they can mark things much better than current methods which use fluorescence. This means that carbon nanotubes can be used as biomarkers, substances that tell us how severe a disease is in the human body, for serious diseases and illnesses, such as arthritis, lupus, celiac, and cancer and can play a key role in pointing out diseases in the future.

As for in vitro, carbon nanotubes are proven to be able to deliver small molecules into the body. Researchers successfully used PEGlyated carbon nanotubes to bring anticancer and antifungal drugs to cells. When cancer cells were targeted with a

toxic drug, the nanotubes brought the drug only to cancerous cells, killing them and getting rid of tumors. This can lead to many widespread treatments and cures for many illnesses and diseases in the future. Carbon nanotubes are also capable of working with both DNA and RNA. Positive charges can be placed on the tubes, which help DNA plasmids bind to them. This allows scientists to transfect proteins, such as GFP, Green Fluorescent Protein, into cells. GFP is like a sharpie for researchers, as they can use it to mark and watch certain parts of cells. Carbon nanotubes can also be used to help siRNA, or small interfering RNA, which is capable of stopping the expression of a gene of choice. This is beneficial because it can prevent genetically inherited diseases like Autism or Sickle-Cell Anemia.. Linking carbon nanotubes to siRNA is a safer and effective way of getting the siRNA into the body. Down Syndrome and Cystic Fibrosis are two other examples of genetically inherited diseases and with the use of carbon nanotubes, the treatment of such diseases can be revolutionary.

Aside from medical applications, there are many other ways carbon nanotubes can be used. A potential use of carbon nanotubes is building an elevator to space. The proposed idea would be composed of carbon nanotubes, and it would extend 22,000 miles above the surface of the earth. An anchor would be on Earth, holding the bottom part down and serving as a loading dock, there would be a massive tube going upward. In space, there would be a counterweight keeping the tube tight. China has pledged to build one by 2045, and Obayashi, a Japanese construction company, wants to build one by 2050.

Carbon nanotubes are an incredibly new, interesting creation that can change many aspects of our world, from the space program to genetic diseases. In vivo and in vitro treatments using carbon nanotubes can save and improve lives. Technological advancements in carbon nanotubes can even make getting into space easier and help prevent and cure cancer and other diseases. Further research into carbon nanotubes is needed, but it is safe to say that they will have a lasting impact on our future.



2018 Physics Nobel Prize: Developments in Laser Physics Awarded to Arthur Ashkin, Gérard Mourou and Donna Strickland

Covered by Arden Chen



ntil the mid-twentieth century, lasers were an exotic concept confined to the realm of science fiction. This year, in 2018, the Nobel Prize in Physics was awarded one-half to Dr. Arthur Ashkin, and the other half jointly to Dr. Donna Strickland and Dr. Gérard Mourou for their revolutionary work in the rapidly growing field of laser optics. Dr. Ashkin, an American scientist, invented and developed the optical tweezer, and Dr. Strickland and her doctoral advisor, Dr. Mourou, co-invented chirped pulse amplification. Stirring admiration, Donna Strickland became the third woman in history to have been awarded the Nobel Prize in Physics, after Marie Curie in 1903 and Maria Goeppert-Meyer in 1963. Many regard this accomplishment as remarkable because women have historically been underrepresented in many STEM fields, especially Chemistry and Physics, and the Nobel has been awarded to only five women to this day. Dr. Strickland demonstrated that females do indeed

have the same potential as men in the sciences, and that they have contributed to the achievements of the human race just as men have.

Dr. Ashkin delivered a major breakthrough in 1987 by disclosing his development of the optical tweezer, a special tool that uses the high accuracy and intensity of laser beams to suspend, or trap, a single particle in space. The suspension of the particle is achieved by the manipulation of Gaussian laser beams, which focus their maximum intensity to the beam center, and decrease in intensity towards the edges, following a Gaussian distribution curve. These lasers focus in on the particle and apply strong scattering and gradient forces onto it in order to hold it in place. The scattering force is exerted in the direction of the beam and the gradient forces follow the direction of the intensity gradient of light towards the strongest intensity in the center. With a strong beam, the gradient force becomes so strong and pulls the particle against Brownian motion -random particle motion due to collisions of surrounding particles –towards the center. Therefore, by the optical scattering and gradient forces, the particle is limited to the focus point of the laser beams, holding a single particle in place.

Other forms of optical traps have proven to be useful in studying individual particles and their behaviors without the interference of other outside forces. Usually, thermal forces from minor temperature gradients push particles in the direction of the colder temperature. For example, Photophoresis, a type of thermal force, is generated by emitted light. In 1970, Ashkin used optical traps to suspend particles in a transparent medium, such as water, in order to study the electromagnetic radiation emanating from them. The optical trap reduced the effect of thermal forces that overwhelm the radiation, allowing Ashkin to concentrate solely on the radiation pressure. Depending on the intensity of the beam, Ashkin was able to trap dielectric particles, some as small as a few angstroms.

The inventions highlighted ... have greatly augmented the potential of the use of lasers across multiple fields of science.

The optical tweezer has also had major effects in biology, allowing scientists to trap single cells in air to study them. In his 1987 paper "Optical trapping and manipulation of viruses and bacteria," Ashkin explained that his research team used optical tweezers to move live single bacteria and view them under high-resolution optical microscopes. In another experiment, he was able to trap the virus TMV, a cylindrical virus with diameter of ~200Å, prepared by colloidal suspension in water. Using laser powers of 100-300 mW, he was able to trap the particles.

In 1988, Donna Strickland released her research on the development of chirped pulse amplification. In the past, lasers reached a point at which they could not become any stronger, as the light could not be amplified further due to the limits of the amplifier. Chirped pulse amplification has strengthened lasers by increasing the potential intensity of laser light. On average, lasers have quadrupled in power every decade thanks to Strickland's innovation. A LASER-Light Amplification by Stimulated Emission of Radiation- relies on the principle of amplifying light to create powerful beams. Chirped pulse amplification stretches out the light waves first, producing a long pulse with a low peak power. At this point, the long pulses become amplified to their peak power, which is possible due to their low frequency. Finally, the waves can be compressed again to their original size, thereby increasing the intensity of the light. The resulting light beam can have powers on the petawatt or even exawatt level, and the power limit increases every year as even more powerful lasers are developed.

By introducing and developing this technique, Strickland and Mourou have broken an important barrier that prevented the advancement of lasers. Their research has had massive effects on the medical field because this technique allows lasers to become much more precise. Chirped pulse amplification results in extremely brief and sharp beams of light, and lasers with such a high intensity can penetrate almost any material with high accuracy, a factor that is crucial for technology in the medical field. Using these new laser technologies, doctors have performed surgeries with much higher precision. After Stephen Trokel pioneered the use of lasers to correct nearsightedness in 1983, lasers were used to cure defects, augment physical features, and perform therapies. Nowadays, lasers are also used to cut specific tissues with minimal bleeding, most commonly in the eye (for near- or farsightedness), as well as during surgeries across the body, such as in plastic or spinal surgery.

The inventions highlighted in this year's Nobel Prize in Physics have greatly augmented the potential of the use of lasers across multiple fields of science. Optical tweezers have created the possibility of closely studying individual particles without interruption and chirped pulse amplification has improved the power of lasers, creating opportunities for lasers to be used in many more fields while also improving the quality and accuracy of medical operations. Drs. Ashkin, Strickland, and Mourou boosted the potential of lasers while they were growing in use, paving the way for more sophisticated technologies to develop today and in the future.





The Violation of CP-Symmetry

Lita Crichton

question that scientists have raised over and over again is: "Why is there more matter than antimatter in the universe?" The Big Bang Theory supports that idea that there was an equal amount of each produced during the creation of the universe. Matter is anything that has mass and takes up space. Antimatter is also matter, except that it is made up of antiparticles called positrons, antiprotons, and antineutrons. For example, a positron has a positive charge while still bearing the same mass as an electron.

Particle physics has relied on the idea that the universe treats matter and antimatter alike. In order to explain this phenomenon, scientists developed CP-Symmetry. The C stands for "Charge conjugation" and the P stands for "Parity". Charge conjugation is the symmetry of negative and positive changes, meaning that if there is initially a positively charged particle, Charge conjugation makes it negative, and therefore, changes matter into antimatter. Parity symmetry is different, as it is the symmetry of coordinates in a multi-dimensional plane, which is a plane that can have two or more dimensions. A two-dimensional plane would have an x and y axis, and a three-dimensional plane would have x, y, and z

"The violation of CP-symmetry...may explain why and how we exist today"

axes. Parity changes the spin, or direction of rotation, of a particle; if the particle originally had a right-handed spin, Parity would give it a left-handed spin, essentially producing the mirror image of reality. In combining Charge conjugation and Parity symmetry, an electron with a "left-hand" spin of speed v (velocity) would be made into a positron with a right-hand spin of speed -v.

Scientists accepted CP-Symmetry until 1956, when Parity conservation was shown to be violated by Columbia University Physicist Chien-Shiung Wu. Parity conservation states that the "law of physics should not change when all the signs the signs of a particle's spatial coordinates are flipped." Therefore, if Charge conjugation and Parity is combined and a particle and a mirror image of its orientation is produced and made the opposite charge, then its characteristics in an atomic reaction should not change. Wu studied the decay of cobalt-60, an unstable isotope of cobalt. Cobalt-60 decays into nickel-60, and it releases an electron as well as an electron antineutrino, a subatomic particle emitted during radioactive decay, in the process. The emission of an antineutrino makes the isotope more stable. In addition, the nickel-60 isotope releases photons, which produce light. Wu created two mirrored arrangements to observe the decay of Cobalt-60 by cooling Cobalt-60 to near absolute zero and then placing the cobalt into a uniform magnetic field. If CP-Symmetry worked, then the photons and the electrons would have been released in the same direction and proportion. However, this did not happen, so Parity was proven to be violated.

Weak interactions, or the weak force, were discovered to be the reason why Parity was violated, however, it still held for strong and electromagnetic interactions. This realization led scientists to question whether any CP-symmetry actually held. Wu's experiment led other physicists to believe that their assumption about CP-Symmetry had been wrong all along. For instance, scientists learned that C symmetry, the symmetry between particles and their antiparticles, must have been violated as well. The C and P transformations conflict with each other through "spin" when added to other particles.

C symmetry was found to be in conflict with P symmetry, but scientists still hoped that CP-Symmetry would be conserved because Charge conjugation and Parity would work together. In 1964, Brookhaven National Laboratory scientists James Cronin and Val Fitch, were studying the decay of neutral kaons transforming pions, which are subatomic particles that are made up of quarks and antiquarks subatomic particles that make up protons and neutrons. Cronin and Fitch's research team found that long lived kaons sometimes decayed into two pions, and sometimes into three pions. CP-Symmetry was violated because the two paths were not produced at equal rates or in equal amounts. The work with neutral kaons continued, and in 1999, BaBar, a scientist at SLAC, and Belle, a scientist at KEK in Japan, began to experiment with decays of B mesons, which are made up of bottom antiquarks. The scientists looked at many different B meson decays and found that there were small differences between how the particles and their antiparticles decayed, further supporting the violation of CP-Symmetry.

The CP violation that was observed in these experiments was so intense and "a million to a billion times too small" for scientists to observe these days. However, with the current improving technology, scientists will be able to learn more about these particle physics experiments in the future. CP-Symmetry was something that was assumed to be true for a long period of time, and the fact that it does not hold true for weak forces was shocking and a huge new idea for scientists. This is because weak forces can allow particles to change identity, unlike electromagnetic and strong forces, which do not allow particles to change identity. The idea of the violation of CP-Symmetry is one very important step on the path to understanding observations of matter and antimatter in the universe, which may explain why and how we exist today.



The European Organization for Nuclear Research's (CERN) Large Hadron Collider beauty experiment (LHCb) is focused on discovering new types of matter such as quarks and tetratquarks. LHCb's primary objective is to investigate interactions between various types of matter and their roles in building the world around us. It mirrors the goals of CERN, an organization that is self-described as "physicists and engineers [who] are probing the fundamental structure of the universe." They research the basic building blocks of the universe and discover new insights into how these different particles interact with each other. To make all these new observations, CERN uses many developing technologies, including particle accelerators.

LHCb specifically has been tasked with characterizing the differences between matter and antimatter. LHCb was created by an abundance of support and collaboration from around 700 scientists and 66 research institutions and universities. The machine works by colliding extremely high energy protons. In order to track the particles during the collisions, the machine is laced with a multitude of subdetectors whose main purpose is to detect the particles that are mainly moving forward. This is a slightly different approach compared to other particle detector sites located within the LHC, such as ATLAS (A Toroidal LHC ApparatuS) and CMS (Compact Muon Solenoid). On these instruments, the entire collision point is typically enclosed with a detector, as opposed to having a series of subdetectors that are placed throughout the unit. The subdetectors are organized such that there is always a distance of at least 20 meters between consecutive subdetectors, starting with the first subdetector, which is placed near the collision point. In the LHCb experiment, a specific type of quark called the "beauty quark" (also referred to as the "b quark") is currently under study. CERN explains that in order "[t]o catch the b quarks, LHCb has developed sophisticated movable tracking detectors close to the path of the beams circling in the LHC," and this "5600-tonne LHCb detector is made up of a forward spectrometer and planar detectors." Due to all these parts, the instrument is 21 meters long, 10 meters high, 13 meters wide, and is located 100 meters below the village of Ferney-Voltaire in France.

Quarks are a basic and essential aspect of physics, as they bond subatomic particles together. The quark model was created in 1964 by Murray Gell-Mann and George Zweig, and it still stands as the most valid and widely used method for classifying different hadrons. According to the general definition of quarks, "quarks are not observed independently but always in combination with other quarks." This is critical because it means that one cannot directly measure different physical properties of a quark (such as mass, spin, parity); instead, one must use the particles that form when quarks are grouped together in order to help us make educated assumptions about their characteristics. There are six types of quarks, known as flavors: up, down, top, bottom, charm, and strange.

Recently, CERN's Large Hadron Collider has made a new discovery: "two never-before-seen particles, as well as hints of another new particle," were discovered. The two new particles are baryons, the fundamental building blocks of the universe,

"The two new particles are baryons, the fundamental building blocks of the universe, protons and neutrons being the two most common examples."

protons and neutrons being the two most common examples. Baryons are composed of three quarks. The first type of newly discovered Baryon, named "buu" ($\Sigma_{b}(6097)^{+}$), consists of one bottom quark and two up quarks. The other type of Baryon, named "bdd" ($\Sigma_{\mu}(6097)$), consists of one bottom quark and two down quarks. Because of their composition, both of these baryons fall into the category of bottom baryons.

Scientists at Fermilab, outside of Chicago, first discovered four bottom baryons in 2006 ($\Sigma_{b}^{+}, \Sigma_{b}^{-}$, Σ_{b}^{*+} and Σ_{b}^{*-}). Until now, nobody has discovered their higher-mass counterparts. These new baryons are the first discovered higher-mass counterparts of the traditionally known particles, estimated to be around six times more massive than a proton!

The third particle observed by LHCb was an exotic meson called a tetraquark. Typically, mesons are composed of two or three quarks and antiquarks. The tetraquark is more foreign to the scientific world. Although the name tetraquark implies four quarks, it is technically composed of two quarks and two antiquarks.

The new particle "was detected together with two heavy quarks in the decay of heavier B mesons.' This tetraquark, called $Z_{c}^{-}(4100)$, does not pass the five standard deviations threshold necessary for validation as a true particle. $Z_c^{-}(4100)$ only passes the three standard deviations threshold, meaning its existence is, at the moment, inconclusive. The results from LHCb are certainly promising, despite the fact that one can't actually confirm or validate the existence of $Z_{-}^{-}(4100)$.

These new discoveries are important as they help scientists move closer to answering questions about the universe's existence and composition. Baryons and quarks are fundamental particles that construct much of the known universe, and the more mysteries one solves about their origins and bahaviors, the more one knows about the universe.

> "These new baryons are the first discovered higher-mass counterparts of the traditionally known particles."

Below: specific combinations of quarks and other subatomic particles (left) form various larger particles.



FALL 2018

Black Holes Ruled Out as Contenders for Dark Matter

MILEN NELIVIGI

"Dark matter remains to be a mysterious part of our universe that is hard to identify. With black holes ruled out due to the lack of observed gravitational lensing and chameleon particles almost surely off the list because of the results of Hamilton and Muller's experiment, one can only be hopeful in the fact that physicists now have fewer options to consider."

Dark Matte

Nonluminous, invisible matter whose existence is only known through its effects on gravity!

Cravitational Waves Detected for the first time at LIGO on September 14, 2015. **F** or all the knowledge that scientists have about the universe, there is even more that they don't know or cannot find. Dark matter, a type of mysterious, ubiquitous particle, comprises a majority of the total matter in the universe, but this does not mean it is easy to elucidate its nature. Physicists have been searching for dark matter in the universe for decades.

After scientists observed that the speed of universal expansion is constantly increasing, they coined the term "dark energy" in 1988 to describe the unseen force causing this acceleration. "Dark matter" was ultimately used in order to paint a picture of another unseen substance, which allowed scientists to explain the gravitational force that visible matter could not account for.

matter could not account for. Physicists at the Laser Interferometer Gravitational-wave Observatory (LIGO), an observatory created for the sole purpose of detecting gravitational waves, detected gravitational waves for the first time in 2015. Gravitational waves are disturbances or ripples in the fabric of spacetime, the three spatial dimensions and time. After confirming that the gravitational waves originated from the merging of two black holes, the physicists noticed that not only were the rotations of the black holes very slow, but their sizes were enormous. These unexpected findings lead scientists to believe that they were of a primordial origin created at the beginning of time. Evidence of a vast population of primordial black holes stirred the hopes of physicists; they thought that these black holes could finally account for the missing dark matter in the universe.

Several years later on October 2, 2018, physicists at University of California, Berkeley, removed black holes as a contender for dark matter. Because an estimated 84.5% of the universe is dark matter and dark energy, there should be an abundance of black holes that would account for this. Furthermore, black holes would create an effect called "gravitational lensing," which occurs when the gravitational force of a large object magnifies light coming from an object even farther away. If black holes accounted for the missing mass of dark matter in the universe, then supernovae magnified by them would be seen fairly frequently. A lead author of the UC Berkeley team, Miguel Zumalacárregui, noted that "You cannot see this effect on one supernova, but when you put them all together and do a full Bayesian analysis you start putting very strong constraints on the dark matter, because each supernova counts and you have so many of them." The farther away the supernovae are and the larger the quantity of supernovae, the higher chance of a black hole altering our perception of it through gravitational lensing.

Astronomers have used Type 1a supernovae, a supernova of two stars orbiting each other, as a standard source for measuring brightness to calculate distance. The effects of dark matter, black hole gravitational lensing, should be apparent for some of these supernovae. However, after performing a statistical analysis of the brightness and distance of 740 of these supernovae, the group at UC Berkeley found that at least eight of those should have been altered by gravitational lensing, but were not. Due to the



surprising results, the team concluded that black holes comprise less than 40% of dark matter. After performing another study with 1,048 additional supernovae, the estimate was revised to reflect that 23% of dark matter could be comprised of black holes. This unexpected and low result led scientists to believe that black holes could not be used to explain the existence of dark matter, nor could candidates similar to black holes, such as Massive Astrophysical Compact Halo Objects (MACHOs). These objects are any form of astronomical body that could explain the seemingly abundant dark matter in the halos of galaxies.

Before the study at Berkeley, explanations for the existence of dark matter constituted a wide range of known objects in the universe, such as MACHOs, incredibly light particles (axions), and Weakly Interacting Massive Particles (WIMPs). Even after progress was made in the pursuit of dark matter, like the omission of black holes from the list, all of the uncertainty surrounding our "dark" universe leaves the question of what dark matter is really comprised of. Some suggest that it is integral in every part of the universe, while others believe that it can come in the form of any number of hypothetical particles.

Another previously promising candidate for dark matter is following a similar path to that of black holes. The theory of "Chameleon" particles were introduced by Justin Khoury of the University of Pennsylvania in 2004. Khoury hypothesized that dark matter particles were "hiding" in the form of chameleon particles. These particles, if proven to exist, would change mass based on the surrounding matter's density, causing it to clump to matter with a weaker force than gravity. Because it would act differently compared to gravity, Paul Hamilton, the leader of the team at UC Berkeley searching for the chameleon particle, came to the conclusion that a machine designed to detect gravitational anomalies built by Holger Muller of the Lawrence Berkeley National Laboratory would be able to detect them. Although many were hopeful that the experiment would shine light on the hypothetical particles, the only force detected in the experiment was gravity, thus almost completely ruling out chameleon particles as contenders for dark matter. This being said, Hamilton and Muller are updating their experiment and it is far more sensitive now. If chameleon particles do not exist, the search for dark matter will continue to narrow.

Dark matter remains a mysterious part of our universe that is difficult to identify. With black holes ruled out due to the lack of observed gravitational lensing and chameleon particles almost surely off the list because of the results of Hamilton and Muller, physicists now have fewer options to consider. A popular explanation for dark matter, other than the ones previously mentioned, is that the dark matter particles have a gravitational pull, yet are non baryonic, and don't interact with light and known matter. Some scientists continue to sift through the possibilities in search for the elusive particle, whereas others believe our theory of gravity is flawed. But regardless of the various viewpoints regarding the existence of dark matter, many efforts to characterize this phenomenon are currently in full swing. The scientists at the European Organization for Nuclear Research (CERN) are using the Large Hadron Collider to generate and study dark matter particles, just one effort out of many in a global attempt to solve the mysteries of our universe.

These particles can change mass based on the density of the matter surrounding them!

A bending of light caused by massive objects as seen by the observer.

NEUTRON TOMOGRAPHY and Polarimetry

BY THEODORE GANEA

n February of 2018, a team led by Morten Sales refined the technique of neutron tomography to allow for Time-of-Flight Three Dimensional Polarimetry—a technique "capable of measuring and reconstructing 3D magnetic field strengths and direction non-destructively... without having to probe the interior of an object."

Tomography, from the Greek word tomos, or slice, focuses radiation onto a very thin slice of a sample between a radiation source and the camera that processes the images. A computer is used to process the thin slices of information by packing them together to reconstruct the composition of the original object. Some types of tomography are used in X-ray and CAT scans. In neutron tomography, instead of shooting x-radiation (a type of light-based radiation) at the sample, a generator is used to shoot a beam of neutrons through an object. Based on the way the neutrons' flight paths are changed when they hit the camera, specialized programs determine the composition of the matter inside the object.

Tomography, and neutron tomography in particular, has a problem: it's blunt and unwieldy. Although neutron tomography has an accuracy of 25 micrometers, this amount is relatively large when considering the standards of modern science. The neutron's destructiveness is a problem when distinguishing between similar objects. If a specific ratio of glucose to galactose is needed in a given medicine, a probing technique that alters the ratio of glucose to galactose is useless and counterproductive. The pharmaceutical producers will have no way of knowing whether the error that their computer shows was caused by the neutrons' destruction or a genuine flaw in the company's manufacturing process.

When very high accuracy is needed, or a fragile object is used, scientists employ polarimetry. Instead of shooting particles at an object and seeing how its flight path changes, polarimetry creates a strong electromagnetic field that changes the magnetic orientation of the object. When the object's magnetic field is polarized, it gives off its own magnetic field. Based on this field, computers can reconstruct the composition of the sample. As soon as the external electromagnetic field is turned off, the sample reverts to normal, so little permanent damage is done.

A drawback with this method is that the applied magnetic field must be known beforehand; results are worthless if the electromagnetic source is faulty. Another drawback is that polarimetry doesn't work in large objects. An international team of nine scientists worked to fix these flaws. Morten Sales, a Danish physician with experience in mathematics and neutron dynamics, led the team. William R. B. Lionheart, the first co-author, led the computer mathematics side of the study. Other major figures were Markus Strobl, a Swiss scientist specializing in neutron scattering and imaging, and Takenao Shinohara, a Japanese scientist who works for the Japanese government's atomic energy agency and heads the J-PARC center.





Morten Sales and his team determined that the best way to fix the flaws associated with neutron tomography and magnetic polarimetry issues was to incorporate elements of both methods into a new approach. Their idea was to calculate the precession of neutrons' flight paths based on the strength of a given magnetic field and the time the neutron spent in that magnetic field. This would allow them to calculate the strength of the magnetic field based on how the neutrons' flight path changed. By calculating the strength of the magnetic field based on the neutrons' flight path, neutrons can pass in the general vicinity of the object without contacting the actual object. The interaction of the magnetic field with the neutrons is recorded, the polarization of the object is reverse-engineered, and the object's composition is reconstructed.

Sales' technique can be used on the same scale as neutron tomography and with the same cutting-edge precision of polarimetry. This new method is particularly advantageous because the neutrons never touch the sample material, only interacting with its induced magnetic field. An object mapped under this technique therefore doesn't undergo extensive damage. The accuracy of the magnetic source does not affect the results because this method only measures the object's magnetic polarization.

Precise imaging of the interior of an object is in high demand. From detective work to radiology, from pharmaceuticals to space travel to archeology, polarimetry and tomography are important tools. Being able to quickly map the body of a murder victim without disturbing the crime scene could lead to more solved cases. Improved fossil dating can help humanity better understand its origins. More accurate pharmaceutical testing could save countless lives by developing better drugs in a shorter amount of time. Over time, the work of Sales' team has the potential to change lives, not to mention impacts on countless other fields in science and technology.



"Polarimetry creates a strong electromagnetic field that changes the magnetic orientation of the object. When the object's magnetic field is polarized, ... computers can reconstruct the composition of the sample."



APPLICATION OF LIDAR AND SG COMMUNICATION IN AUTONOMOUS

HOW WILL THESE VEHICULAR SUSTEMS SHAPE THE FUTURE OF DRIVING?

NATALIE SUEET

s humans advance technology to fit their needs, autonomous driving has become prevalent in today's world, with engineers searching for ways to realize self-driving cars. Engineers typically employ increased sensing and an inter-vehicular communication approach to enable safer and successful autonomous driving. 5G, a communication system that downloads and processes information quicker than 4G technology, enables both of these approaches. For a vehicle to be able to quickly make decisions by itself without a human behind the wheel, communication between the vehicle and other objects has to happen instantaneously. The reaction time that 5G brings to an autonomous vehicle is crucial to the development of this technology.

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asianauto.com

Autonomous vehicles require acute sensing to operate. Light detection and Ranging (LiDAR) is similar to the radar system currently used in most cars; however, rather than sending out radio waves, it emits pulses of infrared light, which humans cannot see, and measures how long it takes the light to return after reflecting from remote objects. LIDAR was first used by NASA's Apollo 15 mission in 1971 to map the moon; it first entered cars in 2005. This process happens millions of times per second, allowing LiDAR to create a point cloud image, which works like Google Maps in real time to identify objects. The car's computing system is then able to anticipate how the car will move in its surroundings.

One of the main reasons why LiDAR is preferable to the average radar system is LiDAR's unique 3D capabilities. Its

"LiDAR is similar to the radar system currently used in most cars; however, rather than sending out radio waves, it emits pulses of infrared light and measures how long it takes the light to return after reflecting from remote objects."

light sensing allows the system to create a 3D image, analogous to how the human eye views objects. LiDAR also does not

face issues that come with other forms of sensing, such as poor performance in snow or other forms of visible light detection. LiDAR's sensing is not only faster but more detailed, allowing for the passenger to have a safe ride.

Another approach to creating safer autonomous vehicles is establishing communications with other vehicles and their surroundings. There are three main ways that autonomous vehicles are able to communicate with their environment: Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Vehicle-to-Pedestrian (V2P), which all fall under the category of Vehicle-to-Environment (V2E). These three categories all use the same type of algorithms to function.

V2E technology primarily focuses on passenger safety and relies on fast communication. A delay in message delivery could lead to a deadly crash, which is a concern for the consumer market. During the past couple of years, the SAE (Society of Automotive Engineers) Dedicated Short Range Communication Technical Committee has created a data dictionary, called SAE J27355, that provides the definition and algorithms for specific V2E messages. Some of these safety warnings include red light violations, curve speeds, reduced speed/work zones, emergency electronic brake lights, and forward collisions. When an accident occurs, the car closest to the accident picks up the signals, then communicates the message to the cars around it.

Autonomous vehicles communicate with each other through a system called Long Term Evolution – Vehicle to Everything (LTE-V2X) system of communication. One thing that is particularly appealing about LTE-V2X is that there is no extra infrastructure required, since LTE-V2X primarily uses existing cellular infrastructure from the vehicle. A second benefit of this technology is that it functions regardless of a network connection. Telecommunications companies such as Qualcomm have focused on improving this technology for several years.

LTE-V2X works through a communication system that relies on high precision clock synchronization. Thanks to this system, all safety messages are relayed to the LTE-V2X system, and digital messages are captured on the edge or level of a clock. Thus, synchronization is crucial for the clock, which is needed for messages to be perpetually picked up. This synchronization system relies on Global Navigation Satellite System (GNSS) signals, which have limited reach, failing to work inside tunnels or underground parking lots.

In order for LTE-V2X to function properly, new technology must be developed.

This technology, known as 5G, is currently under development by several different manufacturers. According to Hugh Martin, Vice President of Strategy at Verizon Smart Communities, it is critical for people to understand how important 5G is to autonomous vehicles, since 5G will connect the communication gap between vehicles and infrastructure. 5G allows data transport at high speeds and low latency (the time delay between the cause and the effect of a physical change in a system) while operating at a high-frequency millimeter wave spectrum of more than 30 gigahertz (GHz), in which data can be quickly transferred. To compare, 4G, the system currently used by cars and devices, takes 50 to 150 milliseconds to transfer and process information. However, 5G technology takes one millisecond or less to process and send information, which is crucial for keeping self-driving cars safe.

Audi, BMW, and Daimler, among others, have already begun to explore and advance this new field of technology. According to WiPro Digital, 5G is predicted to be the biggest game changer for autonomous cars, and by 2020, it is predicted to support 212 billion connected sensors and 50 "Autonomous vehicles communicate with each other through a system called Long Term Evolution - Vehicle to Everything (LTE-V2X) system of communication."



billion connected devices. However, as the complex parts that allow autonomous cars to function uniquely from regular cars are costly, such cars are predicted to be more expensive than regular vehicles. According to Wired, the cheapest LiDAR sensor available right now is \$4,000, and autonomous cars would need several of these sensors to properly scan its surroundings. For most people, an autonomous vehicle

"4G, the system currently used by cars and devices, takes 50 to 150 milliseconds to transfer and process information. 5G technology takes one millisecond or less to process and send information, which is crucial for keeping self-driving cars safe."

would be very expensive to own, which is the main disadvantage that comes with this new technology.

With the rapid advancements in technology, autonomous cars will soon become a reality. People with disabilities will benefit to the largest extent from selfdriving cars. According to a study from the Ruderman Foundation, about one in every five Americans, over 57 million people in total, have a disability. About six million of these people have difficulty accommodating transportation for themselves, leading to issues of job and healthcare accessibility. Autonomous cars would mitigate this problem by allowing around two million individuals with disabilities to access a larger sphere of job opportunities and saving \$19 billion annually in healthcare expenditures from missed medical appointments, the Ruderman study reports. In August 2014,



Nissan's chief executive, Carlos Ghosn, said the company would release a car with "autonomous drive technology" by 2020, but did not give any positive remarks about whether this vehicle could be operated by a disabled person. Nissan spokeswoman Wendy Payne confirmed that the company had not studied the disability issue.

Nevertheless, millions of people around the world will be affected by the reality of autonomous cars. Increased safety precautions will make driving much safer, leading to fewer accidents. 5G technology is quicker than any other communication system, allowing autonomous cars to make quick decisions on the road. Aside from 5G technology, LiDAR provides a more detailed and thorough scan of the car's environment, allowing all movement to be tracked ensuring that every detail on the road is accounted. V2E tracks all possible safety warnings, which include all factors in a car's environment that could lead to an accident. According to the Atlantic, it is estimated that by 2050, autonomous cars could reduce traffic fatalities by around 90 percent. This means that autonomous cars could prevent 29,447 deaths per year in the United States, based on the number of car accident fatalities in 2013. This means that over a decade, almost 300,000 fatalities could be prevented.

As autonomous driving is such a large and complex field, many different engineers, manufactures, and companies are currently creating different solutions to the issue of automobile safety. Both increased sensing and inter-vehicular communication present innovative technology to solve issues beyond the scope of automobile safety, especially with the development of 5G systems.



"Autonomous cars would mitigate the problem by allowing around two million individuals with disabilities to access a larger sphere of job opportunities and saving \$19 billion annually in healthcare expenditures from missed medical appointments, the Ruderman study reports."

PROJECTED AUTONOMOUS VEHICLES IN 2050 DOF TRAFFIC FRIALITIES REDUCED 29, DEPTHS PREVENTED PER YEAR

FALL 2018

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JEARS

SPAN OF





Post Quantum Encryption: The Future of Online Data Storage

Halley Robbins

eople entrust web portals with sensitive personal information often without a second thought. It has become normal to give credit card information to Apple, store medical information online, and enter a home address on a clothing website. However, computers have become exponentially faster at breaking the algorithms that encrypt this confidential data, as the processors powering these machines become increasingly efficient. Although still in experimental phase, when quantum computers become readily available, all encrypted online data will become vulnerable to detection. In light of this technology's disruptive potential, the brightest scientific minds are racing each other to find the ultimate defense against this looming threat.

The concept of encryption is not new to humankind. The Greeks were the first to create ciphers and encryptions that were delivered by hand rather than through computers. They used these methods mainly for military purposes. The ciphers were multipart, requiring several steps and materials to decode the message. The receiver would get the encrypted

C Technology is advancing at such a breakneck pace that it puts these traditional encryption techniques at a higher risk of being hacked. message on paper from the sender and read it by wrapping the paper around the scytale, a wooden cylinder, in order to decipher the code. Without the scytale, a third party interceptor had no way of understanding the hidden message on the paper. This method of sending coded information, while inefficient, was secure because the data could not be hacked by any technology. When online forms of communication were first created, the need for similar cyber protection became an immediate priority, and it still is today.

After decades of innovation, with the introduction of the RSA algorithm in the early 1970s, industry experts were confident that they had created an encryption standard that would be impossible to break. Modern encryption standards use public and private keys derived from multi-digit prime numbers, which cannot be determined easily using the computing power available today. This special property makes the encryption algorithms practically impossible to hack without knowledge of these keys. The computers in use today would need to process billions of possible solutions to decipher these keys. To put this in perspective, a state-ofthe-art computer, running 24 hours a day, would require 70 years to decode the information that is encrypted using the widely acclaimed Advanced Encryption Standard. Based on this, it is easy to understand why industry experts were so confident that their encryption techniques would prove resilient against any brute force attack. However, technology is advancing at such a breakneck pace, that it puts these traditional encryption techniques at a higher risk of being hacked. Early advances in quantum computing have shown that these devices can run algorithms at significantly faster rates than their traditional counterparts. This trend suggests that it is simply a matter of time before computing power reaches a level where no encrypted information exchanged online is safe. Thus there is an urgent need to rethink the encryption standards in use today and to make them quantum computer proof.

Before outlining how people are working to secure online information against quantum computers, it is important to understand the fundamentals of private and public key-based systems that are widely used today to encrypt data. Under the current techniques, online users share their public key with all other users who might want to exchange information with them; they, however, keep their private key confidential. The original information, that needs to be sent, is encrypted using a public key, which turns the data into a scrambled collection of letters, symbols, or numbers. Once encrypted, the message is then sent via the internet to the targeted recipient. Upon receipt, the original message can be retrieved only with the intended receiver's private key. This specific feature of the encryption algorithm ensures that if the message falls into the wrong hands, it does not get compromised.

The ability to intercept an encrypted message relies on figuring out the private key, or decoder for the message. This private key is typically a 128-bit prime number, which makes the encryption process highly reliable. However, now that computers are reaching a level where they can decode these prime numbers through brute force, the future of online safety must be rethought. Among the many solutions that have been proposed, some rely on the principles of quantum physics instead of complex mathematics. One such method of creating encryption keys is called quantum key distribution, or QKD. It involves using photons, packets of energy that are the fundamental building block of light, as carriers of sensitive, encrypted information



Above. The RSA encryption method used public and private keys to encrypt text. A normal computer would take 70 years to break the RSA encryption, but the computing speed of quantum computers means that data that was once thought to be safe is now at risk.

rather than disguising them based on a mapping derived from prime numbers.

A photon's polarization is its orientation, representing specific spinning behaviors in the vertical, horizontal, and diagonal planes. The different spins or polarizations of the photons can denote a number in binary, either a one or a zero. Polarization can change when a photon passes through a certain polarizing filter. Photons produced by light-emitting diodes (LEDs) are not polarized, but by using these filters, the photons can become uniformly polarized, creating an effective mode of communication between the sender and intended recipient of the sensitive information.

The security of this method is twofold. Like any other form of data exchange, using LED-generated photons is an process subject to interception. Unlike other encryption methods, however, the hacker cannot gain information through interception alone. The polarizing filter alters the photon, which is crucial to the secrecy of quantum-encrypted data. Additionally, two photons can be quantum entangled. Altering one photon affects the other regardless of the distance between them. In this way, intercepting and filtering one photon to decode it alters its correlated photon as well. Altering the sent and received encrypted photons discards the encryption key.

Currently, using photons as keys for data encryption is a model rather than a viable solution to protecting online data. One of the main issues of postquantum encryption is the cost of the technology. As computers advance, it is vital to continually advance the forms of encryption to protect currently secure information from the threats of tomorrow's quantum computers.

Currently, using photons as keys for data encryption is a model rather than a viable solution to protecting online data."

The Hardware Approach to Machine Learning

ost computers today are Von Neumann computing systems. Developed in the 1940s, these systems contain a central processing unit, a memory unit, and storage and input/output devices. The separation of the processing and memory units in von Neumann systems mean that while running a Machine Learning algorithm, considerable amounts of data must be transported between the two components. This inefficient method of data transfer leads to not only data congestion, but power inefficiency.

To combat these issues, two groups of scientists have turned to the human brain for inspiration. In the brain, neurons are not continuous but rather joined by structures called synapses, which allow electrochemical signals to be transmitted from one neuron to another. In addition to transferring these signals, synapses will either strengthen or weaken the signals by changing its number of transmitters and receptors. In this way, the synapse familiarizes itself with the process between neurons and is able to simultaneously process and store information. As opposed to storing this data in 0s and 1s, as traditional computers do, synapses have a practically infinite number of possible states and allow for unlimited possibilities to accumulate data. Despite its extraordinary computing abilities, the brain runs on only 20 watts

of power, as opposed to the kilowatts or megawatts of power required by the supercomputers running AI. Researchers from the Harvard School of Engineering and Applied Sciences (SEAS) and IBM took different approaches to constructing computing systems based on synaptic behavior.

The SEAS team built a three-terminal nickelate transistor with the ability to transmit signals while undergoing spiketiming-dependent plasticity (STDP) learning, a common self-learning process in the brain. STDP refers to the ability of synapses to strengthen or weaken depending on the time difference between the input signal (presynaptic strike) and output signal (postsynaptic strike). When a synapse senses that a proper signal is being sent, it becomes more effective and reinforces the strength of the signal; each time a signal is sent, the synapse weight, its number of transmitters and receptors, changes in a manner directly correlated to the time difference between the postsynaptic and presynaptic strikes. The faster the signal is transmitted, the stronger the synapse becomes. For the transistor, the scientists built 'axon', 'dendrite', and 'synapse' terminals mimicking neurons to display this behavior. In the three-terminal model, the conductance of the gate, or synapse, terminal was determined in a similar manner to that of the synapse weight, as a function of the time between the source (presynaptic) and drain (postsynaptic) strikes. These transistors provide nonvolatile memory storage, meaning that they will retain information after having been power-cycled. Conversely, volatile memory (such as RAM, the most common form of storage today) must be constantly powered in order to store data.

Ashley Dai

The SEAS transistor material, SmNiO, (SNO), is such that ratio of Ni³⁺ to Ni²⁺ ions can be controlled by changing the amount of oxygen in the system. This ratio also controls the conductance of the transistor. Researchers used four reversible electrochemical reactions associated with the oxidation and reduction of SNO in conjunction with an ionic liquid, creating a gate terminal of variable conductance. The use of the ionic liquid to store oxygen in both gas and superoxide form allows the transistor to control the amount of oxygen in the gating. The transistor is then able to increase its conductance when presented with negative pulses and decrease its conductance when presented with positive pulses. In tests of the device, the team discovered that 1,500 cycles of -2.5V pulses increased the conductance of the transistor by 1,000%, and that around 900 cycles of +2.5V pulses brought its conductance back to the initial state. To fully achieve

In von Neumann systems, considerable amounts of data must be transported ... This inefficient method of data transfer leads to not only data congestion, but also power inefficiency. Groups of scientists have turned to the human brain for inspiration

synaptic behavior, the source and drain terminals of the device can be connected to a multiplexer which will convert the time between the strikes into a voltaic pulse.

Scientists at IBM took a different approach to their project, developing nonvolatile phase-change memory (PCM) devices. These researchers drew on three levels of inspiration from the brain. First, they drew on the ability to compute and store data within the same structure. Second, they recreated synaptic networks in the brain with arrays of PCM devices, accelerating the training of deep neural nets, a method of artificial intelligence in which computers learn by evaluating thousands of different training examples. Third, they created a semiconductor material from which computing devices for spiking neural networks can be built. Spiking neural networks are unique in that they operate using distinct events that take place at specific points in time, spikes, instead of uninterrupted values, using differential equations to mimic the biological processes of the human brain.

The PCM device built by the team consists of specific compounds of Germanium, Tellurium, and Antimony which have different electrical properties in a crystalline state than in an amorphous state. By applying different amplitudes of electrical pulses, the researchers were able to melt and recrystallize specific amounts of the material, thereby varying the ratio of crystalline material to amorphous material and altering the conductance of the material. In this way, a single PCM device is able to exist in an almost infinite number of states and therefore store infinitely more types of data than traditional computing systems.

Researchers found that arranging the PCM devices in a crossbar array allowed for in-memory computing, the ability to complete computations within the memory of the system. The approximate solutions obtained by the devices were sufficient for most AI tasks; however, computational memory presents a lack of high precision, which becomes difficult to neglect in certain fields. By dividing a computational task into two parts, one in which an approximate answer is found and another in which the precise value of the resulting error is calculated, the team was able to use the concept of mixed-precision in-memory computing to resolve this issue. Mixedprecision in-memory computing allows the PCM devices to be used with von Neumann machines, with the PCM devices giving an approximate answer to the von Neumann

machine, which feeds the error back to the PCM devices and thus allows the devices to return the accurate final answer. Scientists tested this ability and found that compared to CPUs and GPUs (central and graphic processing units), the PCM and von Neumann systems showed up to 6.8 times improvement in speed and power.

Both the nickelate transistor and the PCM device could change the face of AI by creating new learning and data storage methods for algorithms. The SEAS team, in developing a fluidic nickelate transistor with ionic liquid gating, has created a piece of technology that can function between room temperature and 160°C. This function allows the transistor to be integrated into conventional circuits and new computing systems that will be more power efficient. In tests, the PCM device used in conjunction with a von Neumann computer outperformed its solely von Neumann counterparts, performing almost 200 times faster. Both teams created highperforming, energy efficient computing substrates that could help our computers learn like we do.

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