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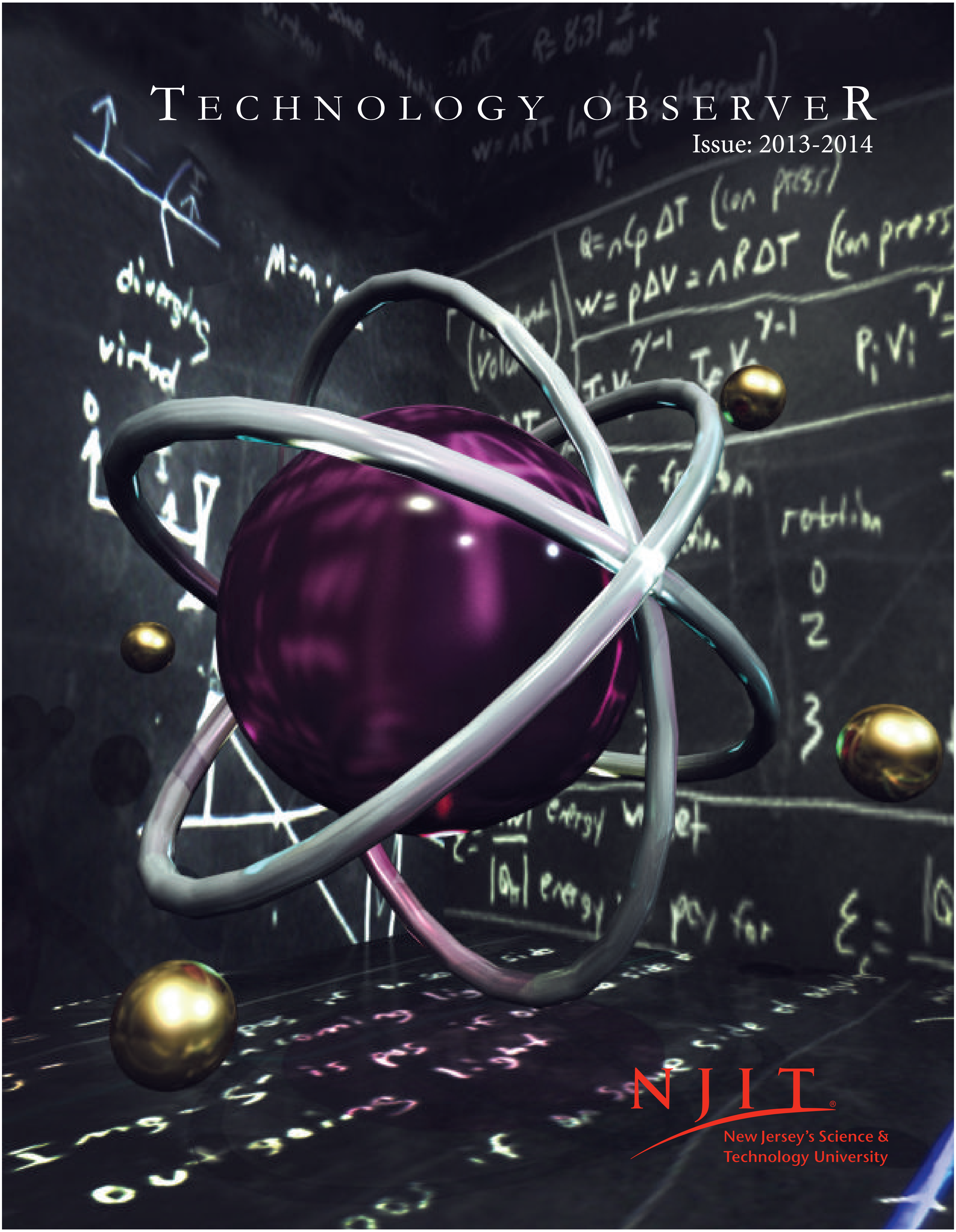

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New Jersey's Science & Technology University

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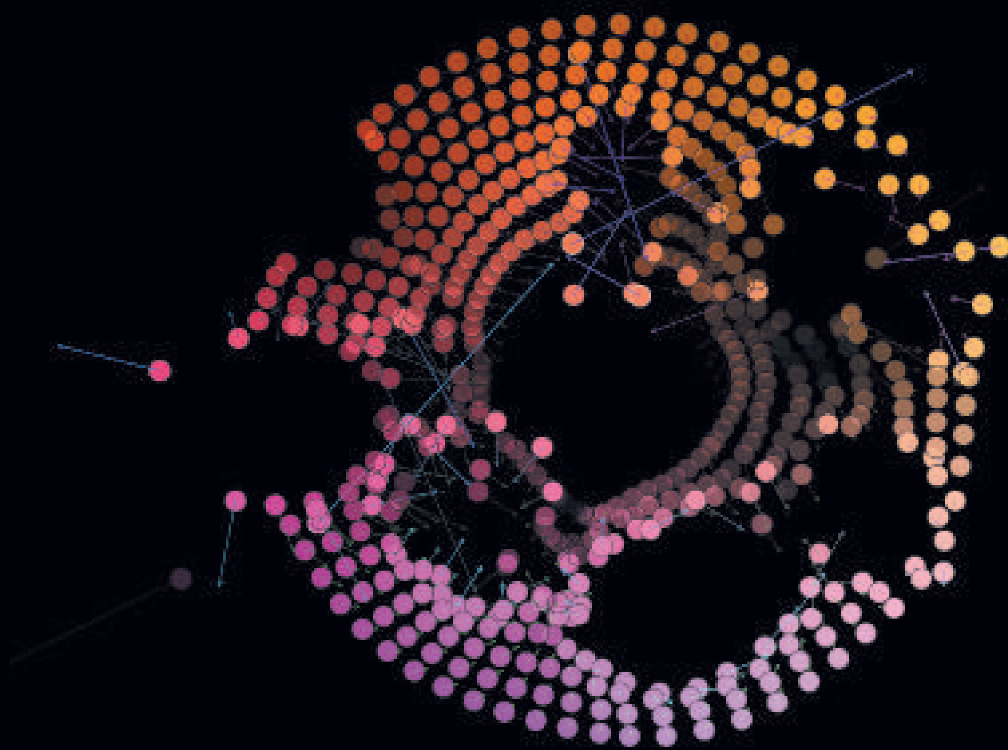

"If anybody says he can think about quantum physics without getting giddy, that only shows he has not understood the first thing about them."

—Niels Bohr

New Jersey Institute of Technology
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New Jersey Institute of Technology (NJIT) is a public research university enrolling nearly 10,000 students. The university offers bachelor's, master's and doctoral degrees in 126 programs through its six colleges: Newark College of Engineering, College of Architecture and Design, College of Science and Liberal Arts, School of Management, College of Computing Sciences, and Albert Dorman Honors College.

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The vision of Albert Dorman Honors College (ADHC) is to engage the brightest students, with the support of the the best faculty, in original research and practice-oriented projects. The ADHC accomplishes this vision by providing a unique environment of inquiry-based learning, a technologically advanced campus, an urban setting, a diverse population, and an educational atmosphere that is erudite and transformational.

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For more information, visit : **honors.njit.edu**

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Letter from the Editor

Dear Reader:

The year 2012 was an exciting one for science. The field of particle physics, perhaps, had the most thrilling year of all. Several theories, models, and equations that had been hypothesized, yet were questioned for many years, were validated. The "discovery" of the Higgs boson, one particular example of such theories, was a global sensation.

While these discoveries have great significance for the physics community, they can also have profound impact on all of humanity from improvements in energy efficiency to biomedicine. Gaining a better understanding of elementary particles and the mechanics of particle physics enables us to better comprehend the physical world around us and our own selves.

Keeping in mind our motto, "Observing the present with an eye on the future," my *Technology Observer* team and I decided to embark on a journey to research and bring to you, our reader, the fascinating new developments in particle physics.

In this issue, you will read about some of the theoretical aspects as well as the practical applications of particle physics. These include cutting edge cancer treatments, the famous Higgs boson, the developing field of quantum computing, and the emerging field of biophysics. We are particularly excited to have had the privilege of interviewing Dr. Frank Wilczek, Nobel laureate in physics.

I would like to thank Assistant Dean Dine of the Honors College for his expert guidance. I extend my sincere gratitude to Dean Dhawan, Dr. Ravindra, Ms. Hoyle, and Dr. Frank Wilczek. This issue of the *Technology Observer* would not have been possible without my team of dedicated editors and writers. I also thank my family for all their help.

I hope you enjoy reading this issue of the *Technology Observer* as much as we enjoyed creating it.

Sincerely,

Kunzang Kazi
Editor-in-Chief

Letter from the Dean

Dear Reader:

Welcome to the 13th edition of the *Technology Observer*, a publication founded, managed, researched, written, designed and edited by Albert Dorman Honors College students. In this issue, they report on recent scientific accomplishments and discoveries in physics as well as on several emerging technologies of high societal impact. Editor-in-Chief Kunzang Kazi and the authors focus on the scientific and technological edge in physics, biophysics, and quantum computing. They also highlight a wide spectrum of applications including cancer treatment.

Physics explains the foundation of our existence. It also provides a knowledge base to learn about nature and everything around us. When Albert Einstein said "Look deep into nature and then you will understand everything," he was pointing towards understanding the physics of everything. It is interesting to note that Niels Bohr believed that "it is wrong to think that the task of physics is to find out how Nature is. Physics concerns what we say about Nature." In this issue, our honors students explore the history of evolutionary concepts in physics that have enabled us to both understand Nature better and develop technologies that we enjoy and use all around us. They also point to potential future technology trends and applications encompassing ongoing investigations into the broad spectrum covered by physics, such as quantum computing, power transmission, and biomedicine.

Tasneem Hossain, in his lead article, "Physics: Then & Now," reviews some of the revolutionary and fundamental principles unfolded by great and inspired physicists from ancient times to the present day, including Albert Einstein, Wilhelm Conrad Röntgen, Marie and Pierre Curie, Max Planck and Sir Isaac Newton. Sarah Rizk sheds light on careers uniting physics and the humanities with a focus on intellectual property issues. Jeffrey Samuel focuses on Hadron Radiotherapy for biomedical applications. In his second article, Tasneem Hossain looks back at the evolution of the universe and investigates the role of electromagnetism and particle theories including the amazing elementary particle phenomenon, the Higgs boson.

A review of another revolutionary concept, quantum computing, is presented by Walter Church IV with a special emphasis on the implications for future computers. "Water or Anomaly?" the article by Gabrielle Rejouis, probes deep into the molecular mysteries of water, which is believed to be one of the fundamental ingredients needed for life to exist on our planet. Jennifer Ligo investigates the role advanced superconductor materials can play in ensuring highly efficient power transmission and reducing energy losses. The role of innovative concepts in particle physics and crystallography is reviewed for applications in biomedicine by Abhishek Trivedi.

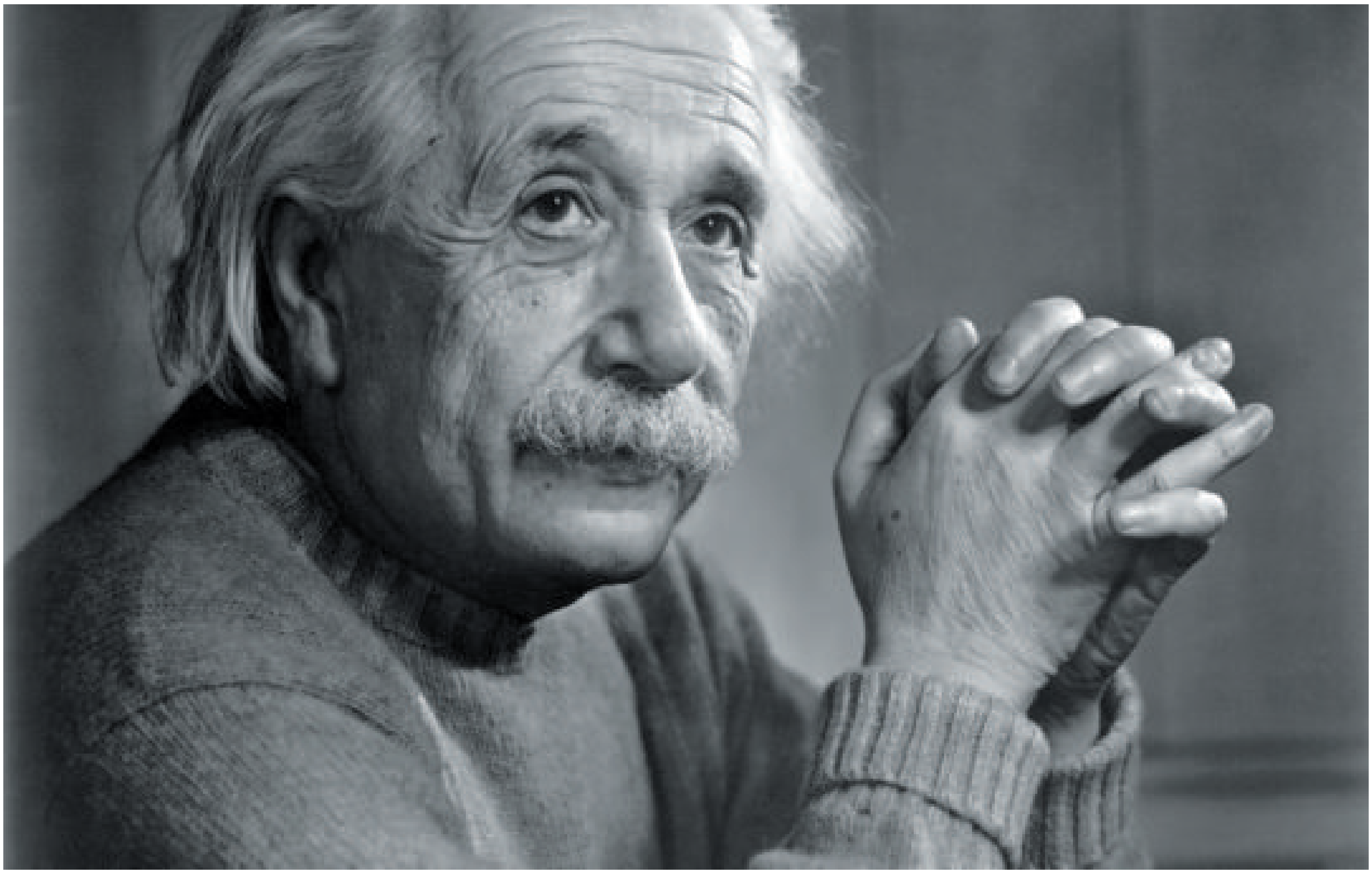
Finally, an inspiring interview with Nobel laureate Dr. Frank Wilczek, the Herman Feshbach Professor of Physics at MIT and winner of the 2004 Nobel Prize for Physics, presents insights into current and future trends in the further evolution of exciting theories and concepts in physics.

The Albert Dorman Honors College is proud to have such talented and dedicated scholars who get involved in research early on to gain insights into cutting-edge technologies, so that they will later be able to take a leadership role in society for the betterment of the quality of life. A recent and related initiative in the Honors College is the Interdisciplinary Design Studio (IDS). This is an enhanced research experience for undergraduate honors students that enables them to learn about and plot the roadmap from innovation to entrepreneurship by addressing critical issues and making a lasting impact on society.

I would like to thank Kunzang Kazi and the entire team of editors and authors for putting together another excellent edition of the *Technology Observer*. It is my hope that you will also enjoy this issue, the fruit of the interest and vision of the participating Dorman Scholars.

Most sincerely,

Atam P. Dhawan, PhD
Distinguished Professor and Interim Dean



Physics: Then & Now

The history of physics dates back to the early ages of civilization. Ancient physicists developed the basic process of the scientific method by utilizing deductive reasoning and observational experiments to explain the nature of the world. The forefathers of physics based many of their theories on religion and philosophy. Ptolemy, for instance, postulated that the earth was the center of the universe and that everything revolved around it; this idea was based on pagan religious traditions. Aristotle began a form of the scientific method by relying on logic and philosophy. These early physicists, even though some of them were wrong in their conclusions, laid the foundation of our understanding of physics today. [1]

It was not until the Scientific Revolution that physics came to its own as a field of science. This began with Galileo's observations of planets with a telescope and his contributions to mechanics and relativity in the 16th century. Later, in the 17th century, Sir Isaac Newton expanded upon the work of Galileo and introduced three laws of motion. He was able to mathematically explain momentum, work, energy, force, acceleration, and many aspects of motion. [2]

In just three hundred years, many major discoveries were made by physicists around the world.

After Newton, physics became more focused on the idea of wave motion and optics. Light and sound were explained in terms of wave motion. Then, in the early 19th century, thermodynamics became the flavor du jour for many physicists. The invention of the engine, based upon the principles of thermodynamics, allowed for advances in transportation and business.

Around the same time, advances in electricity and magnetism were being made by the likes of Coulomb, Faraday, Ampere, Ohm, Gauss, James Clerk Maxwell, and many others. These scientists developed equations explaining various aspects of electricity and magnetism. Their discoveries paved the way for numerous applications, such as light bulbs and alternating current, developed by Thomas Edison and Nicola Tesla, respectively. [1]

In just three hundred years, many major discoveries were made by physicists around the world. By the beginning of the 20th century, most people believed that there was little else left for physicists to do other than refine the minor details of the known laws of physics. The law of conservation of momentum had already been established and the understanding of forces, in terms of Newton's laws, was also increasing. For the most part, the study of physics was thought to be complete.

Many believed that Maxwell's equations were able to explain all the laws of physics; however, there were many shortcomings in that the equations failed to explain issues such as the photoelectric effect. The photoelectric effect is the name for the phenomena wherein directing electrons onto a metal causes the metal to shine at only certain photon frequencies. Although some tried to explain these "gaps" with theories such as the current laws of classical mechanics, these equations were not adequate. Physicists realized that they were far from done and that, in fact, they had much more to do if they were to develop a better mathematical and scientific representation of the universe. This curiosity and ambition led to a revolution in the world of physics. The modern era of physics had begun and research into particle physics started.

The first major breakthrough for particle physics that was truly a catalyst for the field was Wilhelm Röntgen's discovery of X-rays. This discovery earned him the first Nobel Prize in Physics in 1901, and led to Marie and Pierre Curie's discovery of a new element, found through the separation of radioactive elements. Marie and Pierre Curie observed that matter gave out some sort of radioactivity. At about the same time, the study of radiation led Max Planck to theorize that radiation comes in discrete forms of energies called quanta. Few people, however, took Planck's theory seriously. Ultimately, it was Albert Einstein who worked on Planck's idea that energy can be quantized.

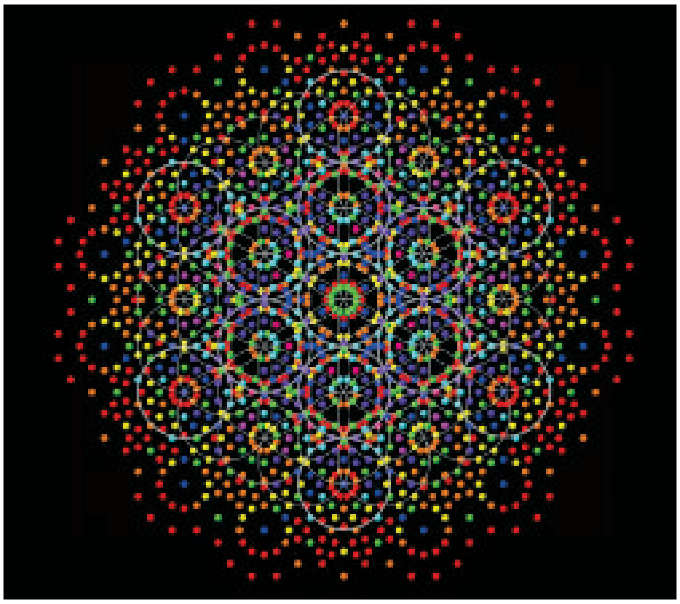
Einstein developed a comprehensive explanation of the photoelectric effect. He stated that light can take the form of a discrete particle, a photon. Furthermore, Einstein formed his two theories of relativity: special and general. The theory of special relativity stated that light is the same in all reference frames, while the theory of general relativity explained what gravity actually is. This theory stated that there is no such thing as gravity. Rather, the feeling of gravity is just the motion of a mass passing through a space-time curvature. Although initially looked down upon, these theories were later proven to be correct and were able to explain some things such as black body radiation, which is radiation that absorbs other forms of radiation.

After Einstein, during the mid-20th century, more research was conducted on the structure of the atom and on Planck's theory that energy can be quantized. It was long believed that atoms were indivisible. However, Ernest Rutherford discovered that the center of the atom is very dense and small. He would also later discover that this was the nucleus. The nucleus consisted of protons and neutrons, which were discovered later by James Chadwick. Another physicist, J. J. Thompson, discovered a sub-atomic particle called the electron. Further investigations were conducted on the electron concurrently. Niels Bohr was one of the first people to suggest that electrons revolve around the nucleus of an atom. However, this was later disproved by the theory that electrons move in random motion in quantum states. As proposed by Heisenberg, the position and velocity of an electron cannot be determined at the same time. Bohr was able to show that it is impossible to simultaneously determine both the momentum and position of an electron.

Around the same time, Planck's idea that energy could be quantized was gaining acceptance. This was in part due to the fact that Arthur Compton was able to confirm that light can act as a particle called a photon. Additionally, Louis de Brogile demonstrated that matter does in fact have both wave and particle-like characteristics. Further theories about quantum mechanics were posited by Paul Dirac, Enrico Fermi, and Erwin Schrödinger. These discoveries made way for the modern era of physics.

Much of modern physics is built on the idea of attempting to unify the universe under one law of nature. James Clerk Maxwell tried to do so but failed. By the late 20th and early 21st centuries, particle physics became the prominent and exciting subfield of physics; most of the research revolved around completing the Standard Model. It was thought that this model would be able to explain how three fundamental forces interact with one another. These forces are electromagnetism, weak nuclear force, and strong nuclear force.

Furthermore, physicists believed that the Standard Model would be able to explain all the fundamental particles that exist in the universe, including



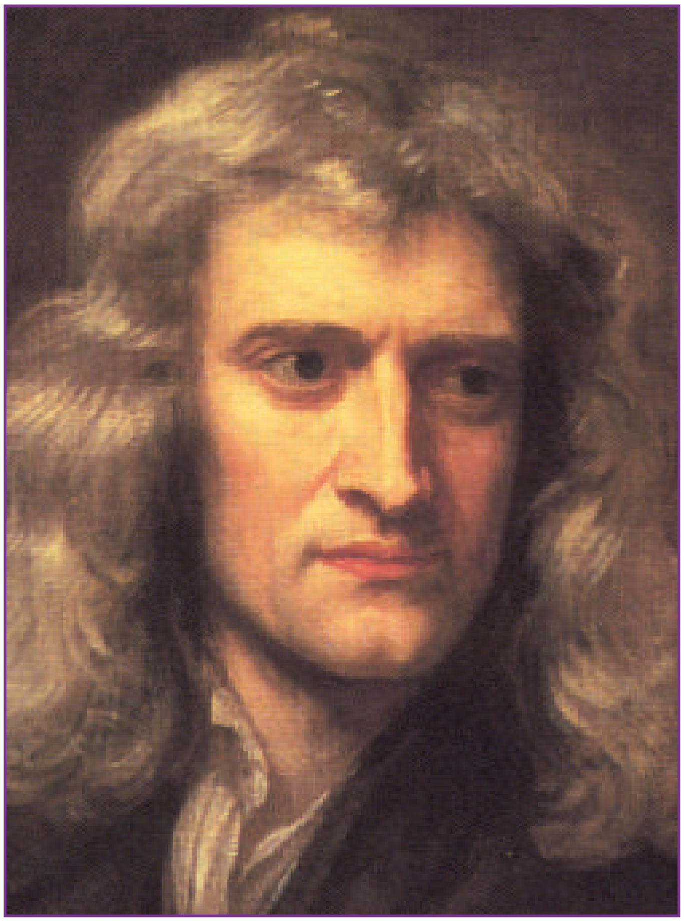
Visual representation of E8 or the Theory of Everything.

the theorized Higgs boson. Recently, CERN, the European particle physics lab, has cautiously speculated that they have discovered the Higgs boson, pending further confirmation. [3] Once the Standard Model is completed, physicists will then have a comprehensive theory of the microscopic world.

Having accomplished this, physicists will perhaps shift their research to try to combine the three fundamental forces with the fourth one, gravity. This Unified Theory of Everything would then be able to explain the universe with just a set of a few mathematical equations. Currently, research is being conducted on string theory. This theory, which attempts to explain how general relativity and the Standard Model are connected, states that the universe is made up of tiny looped strings that constantly vibrate. If this theory is indeed confirmed, then our understanding of the physical properties of the universe would be complete.

The goal of most physicists, dating back to Sir Isaac Newton, was to try to explain the universe in a set of a few equations. As the field evolved, so did that thought process of the world. Physics now has the ability to explain the very large as well as the very small. If and when the Theory of Everything is discovered, the goal of physicists, from throughout the ages, will have been achieved. Physics would be complete. ■

***Tasneem Hossain** is a sophomore majoring in electrical engineering.*



Career Spotlight: Science & Law

When presented with the words law and physics, most people may feel the only connection between the two seemingly unconnected subjects is the word law. Physics, for instance, utilizes the term law to denote some of the most fundamental rules of the universe such as Newton's laws of motion which describe the relationship between forces acting on bodies and the path of forces in motion. However, with the ever-changing world of scientific and technological advancements, physics and law are becoming, each day, evermore linked beyond just mere semantics.

This growing interconnectedness between the fields of physics and law has become evident with the advent of particle physics. Research on particle physics, a branch of physics that studies the interactions of particles that are the building blocks of matter, has been expanding rapidly; currently, most of the research has been focused on subatomic particles and the concept of particle accelerators. While law is associated, generally, with the humanities, criminal justice, and political science, there has been an increasing demand for newly minted lawyers to have a strong background in science as well. As more laboratory results are obtained and new conclusions and theories are proposed along with a simultaneous growth of litigious culture and public involvement in science, intellectual property (IP) lawyers become essential to ensure the protection of an individual's research. Government-issued patents provide scientists this protection of intellectual property.

Government-issued patents provide scientists this protection of intellectual property.

A patent, a form of intellectual property, is granted by a country to an inventor in exchange for public disclosure of their invention. Patents grant inventors (in the country of their residence) exclusive rights that allow them to protect their own ideas for a limited time (the "life" of the patent) from others who could otherwise, potentially, use, manufacture, and or sell their inventions. Countries provide this protection in order to encourage sharing of ideas to spur innovation and economic growth.

Currently, the World Trade Organization (WTO) has an agreement on trade-related aspects of intellectual property rights. This means that any state that is a member of WTO should be able to obtain a patent for its invention in the field of technology in order to protect their original ideas from being stolen by other international states. Every nation in the WTO possesses a patent office responsible for that nation's patents. Each nation's office grants these patents (the patent office of the U.S.A. is the United States Patent and Trademark Office (USPTO). Obtainment of patents and other legal proceedings such as infringement of patents is handled by intellectual property lawyers.

IP lawyers, which include patent lawyers and copyright lawyers, are among the highest paid attorneys. Patent lawyers, in addition to representing clients in procedures related to patent law, handle cases dealing with product liability and torts. They are qualified to prepare exhibits used in trials, serve as witnesses, and should the need arise, cross examine scientists. These lawyers must bring their knowledge in science to the courtroom to establish credibility.

There are many educational differences between a regular lawyer and a patent lawyer. While general attorneys can enter the field with education in just about any subject, IP lawyers, if they want to practice in front of the USPTO and obtain patents on behalf of their clients, they must meet requirements established by the USPTO. They must either have technical training or a background in the sciences through pre-approved bachelor's degree majors or by completing a certain amount of semester hours in science classes. They are also required to obtain proficiency in at least calculus. After taking the Law School Admission Test (LSAT) and attending law school, they must pass the patent bar exam, a two-part, six-hour examination which tests knowledge in the rules and procedures of practice at the USPTO. Those who pass this bar exam become authorized to practice in front of the USPTO. [1]

One major patent case arose recently, when Luis Sancho, a Spanish journalist, and Walter Wagner, a retired safety officer, filed a lawsuit against, among others, the United States government's Department of Energy and the European Organization for Nuclear Research (CERN), an international organization that operates the world's largest particle physics lab, regarding the Large Hadron Collider (LHC). [2] The suit was filed due to concern over the safety of the particle accelerator. Particle accelerators have been a source of controversy since their introduction.

Wagner and Sancho believed that the risk of the LHC's predictions being incorrect was much greater than was being assumed. This, they felt, could potentially lead to a major global catastrophe and thus was grounds enough to file a suit. The plaintiffs questioned what the consequences might be if scientists had overlooked something. They also speculated over the legitimacy of both the theories and the aftereffects of the LHC. Wagner had worked in nuclear medicine and had a degree in physics from Berkley, but Sancho, a science writer, possessed almost no background in particle physics. [3]

The case was filed in a Hawaiian district court in an attempt to delay the start of the LHC. The first argument described the risk of an LHC creating microscopic black holes that would exist for a fraction of a second and then decay. Sancho and Wagner worried that millions of black holes might draw other matter together and grow bigger. Another concern lay in smashing protons together at enormously high energies. This type of collision results in combinations of quarks, the particles of which protons are made. Sancho and Wagner worried that a combination known as a strangelet, which is a hypothetical particle consisting of a bound state and strange quarks, could theoretically turn everything with which it came into contact into a strangelet as well. [4]

The last concern was related to the suggestion that high-energy particle collisions could form massive particles that only have one magnetic pole (only north or only south) instead of the natural north-south magnetism. Why would this be significant? It was thought that if such particles were created by the LHC, it could start a reaction that would convert atoms into other forms of matter.

Since then, the physics community has wholly dismissed each of these theories. They have conducted in-depth risk-assessment studies on particle accelerators and have concluded that "there is no basis for any conceivable threat." [5] Physicists have said that these concerns are more likely to happen in nature than occur as the result of an LHC disaster. The evidence for this lies in cosmic rays which have been traveling at far higher energies than those that would be produced at the LHC. Cosmic rays are high-speed and high-energy particles, which originate in outer space outside of the solar system. These rays have been bombarding Earth for billions of years with no known adverse effect.

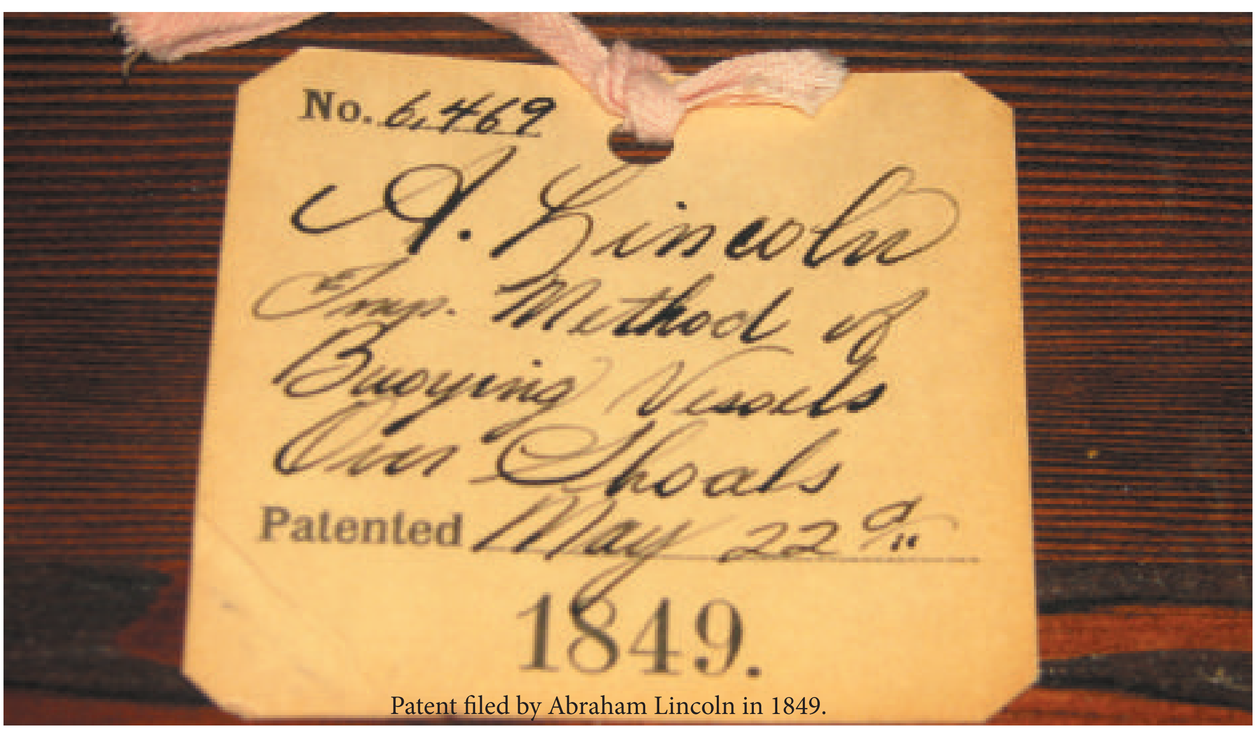
An appellate judge, a judge who has the power to hear an appeal of a trial court judge's decision, eventually dismissed the lawsuit. The judge found that Wagner had no standing before the court. According to the decision, Wagner failed to demonstrate how the LHC could be a "credible threat of harm." Threat of harm in a court of law involves a perception of injury, where harm is defined as physical or mental damage, or a material or tangible detriment or loss to a person. Because Wagner failed to provide evidence of a legitimate threat of harm, the court had no legal responsibility to act.

The decision was also important in establishing jurisdiction. The United States government could not enforce any decision that the judicial court made, in general, and regarding the issue of credible threat, in particular. If threat of harm cannot be established, the court has no standing to provide or enforce a ruling. Furthermore, as the U.S. government would not have controlled the operation of the LHC, it was not the correct party against which to bring action. The U.S. government had no jurisdiction with regard to this matter. Wagner and Sancho were, therefore, wrong in filing their case in a Hawaii district court. The plaintiffs, Sancho and Wagner, should have established an injury in fact or a credible threat of harm in order to file a suit, and the suit should have been filed within the correct jurisdiction in an international court.

Ultimately, CERN (established in 1954 and based in the northwest suburbs of Geneva on the Franco–Swiss border) proposed and constructed the Collider, albeit with some support from the U.S. government. CERN's main function is to provide particle accelerators and other infrastructure needed for high-energy physics research. The U.S. government enjoys observer status on the CERN council; however, it does not have any control over CERN or its operations as CERN maintains total ownership, management, and operational control of the Collider. CERN had never been properly served, meaning that they were never informed nor brought into the court as a party.

Even if the court had rendered a decision in Wagner's favor, such a ruling would have had no impact on CERN or the Collider's operations. Because of this, the case was dismissed on grounds of jurisdiction.

There have been numerous patent law cases presented before the Supreme Court dealing with the issuance of patents, the enforcement of patents, and the role of State and Federal laws regarding patents. One of the earliest cases was 1853's *O'Reilly v. Morse*, which dealt with the development of the law of patent-eligibility. Other important patent law cases include 1908's *Continental Paper Bag Co. v. Eastern Paper Bag Co.*, which held that patent holders have no obligation to use their patent. *The United States v. General Electric Co.* case of 1926 determined a patentee may lawfully fix the price at which the licensee may sell the product. *Diamond v. Chakrabarty*, in 1980, ruled that a genetically modified micro-organism is patentable, and *SRI International, Inc. v. Inter-*



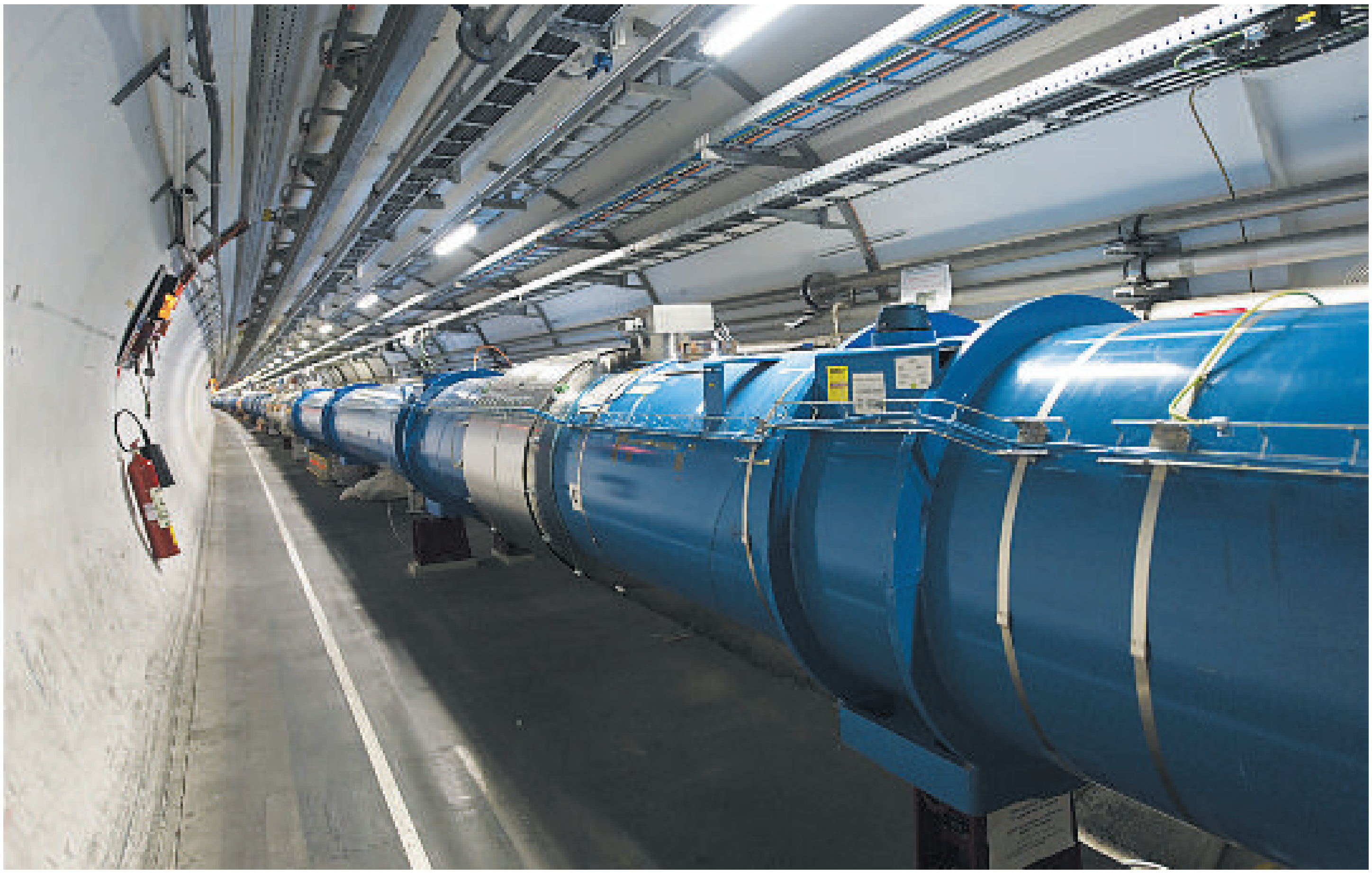
Patent filed by Abraham Lincoln in 1849.

net Security Systems, Inc., in 2008, set the precedent as to whether unpublished papers stored on file transfer protocol (FTP) servers constituted a prior art, in which case, the patent would be considered void.

As the field of science delves further into research and experimentation that could have physically and economically catastrophic consequences for companies, populations, and individuals, science will continue to become further intertwined with the legal system. This will be necessitated by the need for scientists and researchers to protect original ideas and to ensure the safety of the people. Legal actions also often provide a need for careful review of scientific ideas which can in and of itself push science forward and to make sure that scientific experiments are safe.

Scientists are needed in law to help with the issues and complex subjects that may not be fully understood or accessible to the traditional lawyers, judges, and juries who are mainly trained in the humanities. As the public gains easier access to scientific information, experiments become more complicated and seemingly "threatening," and replicating ideas becomes easier, the general public will not merely connect physics and law by an etymological factor. Both science and law will grow ever more interdependent. ■

Sarah Rizk *is a freshman majoring in pre-law.*



Hadron Radiotherapy

Conventional radiotherapy has been used for many decades as a part of cancer treatment to control or kill malignant cells. Curative for a number of different cancers that are localized, radiotherapy is often applied to tumors because of its ability to control cell growth. In conventional therapy, radiation works by destroying DNA of exposed tissues which in turn leads to the tissues' death. [1] The problem with this type of procedure is that it leads to the death of both malignant and healthy tissues. In fact, if a full dose of radiation was given to a patient, severe injury or even death could result. Administering fractional doses is a good way to avoid this problem. As such, conventional radiotherapy is administered in fractions over multiple visits so that normal cells have time to repair themselves between treatments. Is there, however, a better solution that spares healthy tissues and is less time consuming?

Many medications taken by individuals tend to do more harm than intended, so finding a method that eliminates only the problem is a breakthrough for the world of radiotherapy. Patients receiving conventional radiotherapy have always been faced with the fact that, for the malignant tissue to be removed, healthy tissues also are indiscriminately affected by radiation. This puts cancer patients through much mental, emotional, and physical stress, which is often debilitating. A possible solution to this problem is hadron radiotherapy (also known as particle therapy), which is thought to leave healthy tissue unharmed. With this advantage, the medical practitioner would not need to worry as much about possible harmful side effects because the treatment would focus on destroying only the DNA of malignant cells. Also, normally, the required breaks between conventional radiotherapy sessions slow down the treatment process and kill more cells than needed. This new type of treatment would save patients time and keep them from having to go to the hospital multiple times for just fractional treatments. Such a process would allow for faster and more efficient treatment.

Bob Wilson, in 1946, published an important paper on the innovative idea of hadron radiotherapy.[2] His idea is considered to be one of the best practical applications of theoretical knowledge to better help individuals facing painful cancer treatments. Wilson came to understand that protons coupled with charged hadrons would lead to a better distribution of radiation dosage during treatment. His idea started a new view of how conventional care can improve. This led to the beginning of hadron radiotherapy in 1954 at the University of California, Berkeley, when human exposure to accelerated protons and alpha particles began. Over the next thirty years, clinical trials were conducted on more than 1,500 patients. The results of these trials were controversial. Some were positive and some not.

In order to gain a better understanding and appreciation of hadron radiotherapy, one needs to understand the physics behind this complex method of radiotherapy. Hadrons are composite particles made up of quarks, anti-quarks, and gluons all held together by strong force. [3] Two main families of hadrons exist and these are baryons and mesons. Baryons, which include protons and neutrons, are composite subatomic particles that consist of three quarks. Mesons are hadronic subatomic particles composed of one quark and one anti-quark held together by strong interactions.

The fact that the family of hadrons includes both protons and neutrons contributes to the controversy of the previously mentioned clinical trials. To get a basic understanding of protons and neutrons, one must understand how they are composed of quarks and anti-quarks. Quarks, subatomic particles, carry a fractional charge, and an anti-quark is exactly as the title describes, an antiparticle of a quark. Protons are made up of two up quarks, a down quark, a large number of gluons, and quark-anti-quark pairs. While neutrons are very similar to protons, a neutron has one up quark and two down quarks in addition to its numerous gluons, and quark-anti-quark pairs.

So how does hadron radiotherapy work? It works by sending a beam of charged particles, which could be protons, neutrons, or heavy ions to regions where the tumors are located, which in turn kills the cancer cells. Particle physicists have noticed that heavy ions have higher relative biological effectiveness. Relative biological effectiveness is a measure of the ability of a type of ionizing radiation to cause a biological effect relative to a different form of ionizing radiation. Heavy ions have a potential advantage over protons in that they have an increased relative biological effectiveness on the tumor in comparison to the effect on the surrounding healthy tissue. [4] Heavy ion therapy uses, as the name suggests, more massive particles (particles heavier than protons or neutrons) such as carbon ions.

Research has continued to analyze this process and perfect the distribution of the beam. To conduct research on how well hadron radiotherapy works, particle physicists use many tools. One tool used by them is called the Bragg's peak, which is a marked peak on the Bragg's curve. The Bragg's curve plots the energy loss of ionizing radiation, such as that employed by hadron radiotherapy, during its travel through matter. By looking at Bragg's peak, one can estimate a more targeted beam on the tumor thereby preventing damage to healthy tissue. Hadron radiotherapy thus maximizes the efficiency of treatment by focusing only on the region of prime concern which is where the tumor is located. This characteristic is thought to separate hadron radiotherapy from conventional radiotherapy.

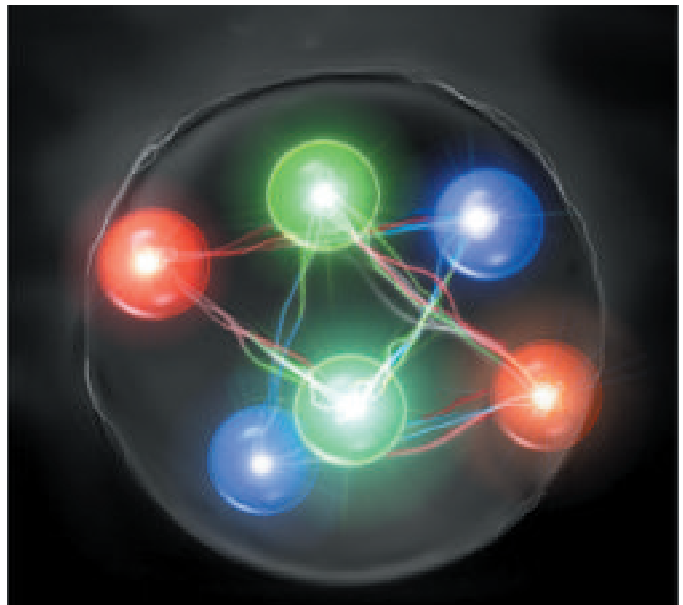


Image of a dibaryon—a special type of baryon.

Particle physicists believe that hadron radiotherapy could, theoretically, be an answer to almost every problem that conventional radiotherapy poses. In reality, however, the application of many of these theories does not result in the predicted desired outcome. Although particle physicists believe that they can develop the idea of hadron radiotherapy to benefit many cancer patients, a few problems remain.

For example, scientists still disagree about the overall benefit of the use of hadron radiotherapy in comparison with the use of conventional radiotherapy. For the most part, the immediate positive results of hadron radiotherapy were clearly defined, and patients, who underwent this treatment, saw improvements such as tumors decreased radically in size. However, while many particle physicists believe that no serious side effects exist, a few think that not enough long-term research has been conducted to show the possible detrimental side effects that could result in the future. Medical professionals have also noticed some negative symptoms that may be correlated with its use. Particle physicists are currently working on conducting research to observe and measure the severity of these possible side effects. [5]

Also, radiotherapy with hadrons has been shown to produce a large number of neutrons which, theoretically, could have the potential to create new cancers and cause other harmful effects. [5] Physicists have seen that very high energy neutrons can impart damaging radiation doses to patients' tissues and organs. These negative aspects are some of the major concerns for patients who are currently being treated with hadron radiotherapy. However, there is no conclusive data linking hadron radiotherapy with these detrimental side effects which include shorter life spans, malignant cell transformation, or even genome damage.

While both conventional radiotherapy and hadron radiotherapy are used to treat different types of cancers around the world, the treatments associated with hadron radiotherapy continue to be implemented without a complete understanding of the potential hazardous effects on patients. Additional research is required to determine if this therapy has more harmful side effects in comparison to conventional radiotherapy. If research proves that there is a direct correlation between hadron radiotherapy and side effects that are predicted to be associated with it, envisioned advantages of hadron radiotherapy over conventional radiotherapy would be diminished.

Is hadron radiotherapy therefore worth the risk? Since much of the data that seems to show that hadron radiotherapy might be dangerous is inconclusive, many patients are still going through with the procedure. Believing that this cutting-edge technology will provide them with the treatment that will have the best possible outcome, some patients feel that it is their best option. Not many researchers have focused on the production of secondary neutrons, which could perhaps be the source of all the detrimental effects.

As a result of the clinical trials, researchers have very recently actually seen that the production of secondary neutrons can possibly lead to new cancers. With greater understanding of this potential problem, experts will be better able to inform patients of some potential negative effects before administering the treatment. Although these side effects are a problem currently, scientists believe that, with further research, these problems can be eliminated and that hadron radiotherapy can have the advantages that it is theoretically believed to possess.

The prospects of hadron radiotherapy are very bright and with the current research being conducted, the future could indeed be great. Centers offering this new innovative treatment are opening in many parts of the world. Many hospital-based centers providing hadron radiotherapy are under construction in countries such as the United States, China, Japan, Germany, Italy, and Korea. [2] Three hospital-based hadron radiotherapy systems exist in the United States and four hospital-based systems exist in Japan. A form of hadron therapy, proton therapy, which uses a beam of protons to destroy cancerous tissues, is currently expanding at a very high rate, and laboratory-based centers are growing in popularity. Advancement of new technologies is making hadron radiotherapy an option for many individuals seeking a cure using a new method of treatment instead of the existing conventional methods.

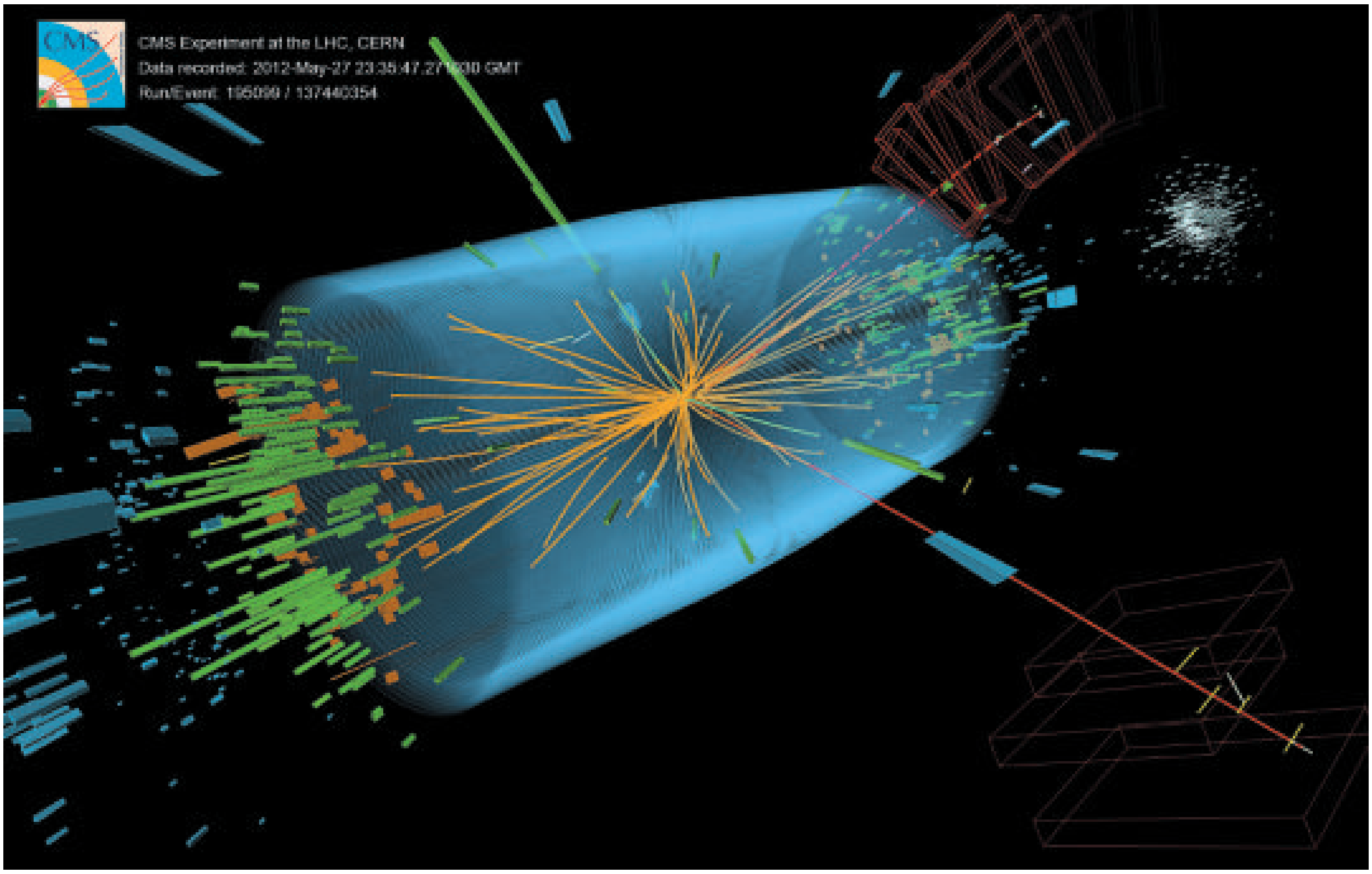
Particle physicists believe that hadron radiotherapy could, theoretically, be an answer to almost every problem that conventional radiotherapy poses.

The use of carbon ion therapy, an important type of heavy ion therapy included under the umbrella of hadron radiotherapy, is also expanding rapidly around the world. There are already two hospital-based centers in Japan, and other new centers that will house these nascent technologies are also under construction in France, Austria, Italy, and Germany.

Funding for these new technologies has increased rapidly, because many individuals have seen the results of this treatment. Due to the work of particle physicists, the understanding of new radiotherapies is becoming available to the general public. It appears that it is not only up to particle physicists to make new discoveries that will contribute to the world in general and hadron radiotherapy in particular. But it is also up to the medical practioners and their patients.

There must be a collective effort of individuals from all fields of science to devise solutions through which many people will benefit. More efficient ways that do not place greater stress than needed on the patient are being developed to treat diseases such as cancer. Hadron radiotherapy is quite possibly the new face of radiotherapy. With the help of particle physicists, it could become a great tool to fight cancer. ■

Jeffrey Samuel *is a sophomore studying biology.*



The Higgs boson

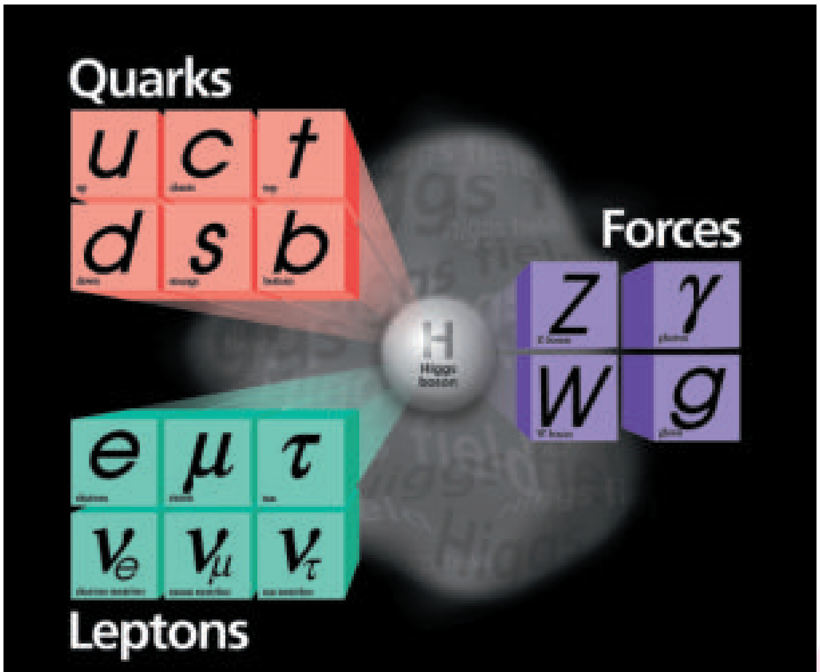
Particle physics deals with matter at the subatomic level. It investigates how forces interact with particles of varying masses. Particle physics postulates that all living matter consists of tiny building blocks even smaller than neutrons, protons, and electrons. These elementary particles such as quarks, bosons, and fermions are, in fact, the building blocks of neutrons, protons, and electrons. Some of these particles are very massive, in the sense that they possess a mass, while others are completely massless. The part that interests physicists is the interactions between elementary particles. Physicists conduct experiments to determine how these particles move, collide, and transfer energy and momentum to one another. All of these interactions or variables relating to these elementary particles can be summarized by the theory of the Standard Model. So, in essence, the field of particle physics is the study of the Standard Model.

A key question that arises in particle physics is, "How do subatomic particles obtain their mass?"

A key question that arises in particle physics is, "How do subatomic particles obtain their mass?" Studying these elementary particles also raise further questions such as, "Why are some particles massive while others are not?" Within the context of the Standard Model, it is predicted that there exists a particle that can give other particles their mass. This particle is called the Higgs boson. Often dubbed the "God Particle," this type of theoretical particle has the ability to give other particles their respective mass. It is one of the basic building blocks of the Standard Model.

Theorized by Peter Higgs in the 1960's, the Higgs boson is being sought with billions of dollars of research funds. Until recently, this particle has only been proven in theory. However, scientists at the European Organization for Nuclear Research (CERN) believe that they have, pending further testing, finally found this particle. This particle could explain so much about how the universe was formed and how the Big Bang came about. Most people are unaware of the significance of this particle. There is still so much mystery that surrounds it. If the Higgs boson is all that it is claimed to be then this particle could explain how matter, and therefore life, gets its unique characteristics.

In order to understand what the Higgs boson actually is, one must look at the bigger picture and comprehend the Theory of the Standard Model. This theory is the broader theory that explains the universe at the subatomic level. Proving this theory is the greater goal of particle physicists; discovering the Higgs boson, although essential, is only part of the journey. In order to understand the Higgs boson and to gain a better understanding of the Standard Model itself, one must also understand the other parts of the Standard Model.



Representation of the 12 elementary particles and 4 forces. Photons and gluons do not interact with the Higgs boson, and they are not anchored on the Higgs boson.

When one examines the structure of the universe and explores its components at extremely microscopic levels, one realizes that all matter and its interactions consist of particles. These particles can be divided into three types of families: quarks, leptons, and field (force) carrying particles. (It should be noted that these three families are further categorized into two groups: bosons and fermions, which will be explained later). Quarks and leptons are particles that make up matter. The basic difference between these two types of particles is that quarks have fractional charge and leptons have integer charge.

In the Standard Model, there are six "flavors" of quarks. They are up, down, top, bottom, charm, and strange. Furthermore, the Standard Model states that leptons also have six particles. They are electrons, electron-neutrinos, muons, muon-neutrinos, tau, and tau-neutrinos. These elementary particles combine to form composite particles which in turn make up matter and all the parts of the universe in which humans live.

In the Standard Model, the three families of particles stated above are further split into bosons and fermions. Bosons are particles that have integer spin numbers, the specific value of which denotes a specific electron orbital, and have the ability to share the same quantum state, the state that the electron is in, among multiple bosons. They do not follow the Pauli Exclusion Principle which states that two particles cannot occupy the same state. Rather, these particles follow the Bose-Einstein Statistic which describes where the particles occupy a given state. On the other hand, fermions are particles that have odd integer half spin numbers and do not have the ability to share a quantum state among multiple fermions. Fermions follow the Fermi-Dirac Statistic, an equation that gives the probability of the electrons' locations. Leptons and quarks are considered to be fermions, so all matter particles are considered fermions. The third family of particles, field (force) carrying particles are considered bosons; specifically they are called gauge bosons.

Field (force) carrying particles, as the name might suggest, are particles that create forces and deal with the interactions of other matter particles. These countless particles create fields that produce a force among bodies of objects. In the universe, there are four fundamental forces: electromagnetic, weak force, strong force, and gravity. The Standard Model accounts for electromagnetic, weak force, and strong force. Each of these forces is associated with a boson. Electromagnetic force is associated with photons, weak forces with the W and Z bosons, and strong forces are represented by the gluon. There is also a theoretical particle associated with gravity called the graviton, which has not yet been discovered. The way these forces work is by "matter particles transfer[ring] discrete amounts of energy by exchanging bosons with each other." [1] These forces make up the gauge bosons of the Standard Model.

The Standard Model is the theory that resolves three of the four fundamental forces of the universe. It does not, however, discuss the issue of dark matter or the fourth fundamental force, gravity. These other factors, specifically gravity of the universe, are explained by Albert Einstein's theory of general relativity. It should be noted that if all four forces are resolved into one "Theory of Everything" then the entire universe can be explained.

In essence, the Standard Model is the theory of the universe at the microscopic scale; it explains how matter is composed and how particles interact. The Standard Model is composed of sixty-one particles, a mixture of bosons and fermions. Sixty of these particles have been discovered and confirmed. The one particle that scientists are still looking for is the key building block of the Standard Model, and this particle is the Higgs boson.

The Standard Model is a comprehensive theory that clearly defines the forces of electromagnetism, weak nuclear force, and strong nuclear force. However, a piece of the puzzle relating to the masses of the W and Z boson of the weak nuclear force and the photon of the electromagnetic force is still a mystery. Physicists have confirmed that "electricity, magnetism, light and some types of radioactivity are all manifestations of a single underlying force called, not surprisingly, the electroweak force. But in order for this unification to work mathematically, it is essential that the force-carrying particles have no mass." [1]

Based on previous experiments, physicists know that photons and the W and Z bosons differ in mass significantly. "The two mediators of the electroweak interaction, the photon has no mass but the W and Z bosons do. Because of this mass difference, the electromagnetic and weak forces are quite distinct at low energies but become similar at very high energies when the rest energy is negligible relative to the total energy." [2] The question that arises from this observation is: "Why do certain particles have a certain mass associated with them?"

The question was answered by Peter Higgs, who proposed that all particles are originally massless. These particles eventually gain their mass through their interaction with an invisible field called the Higgs field. The Higgs boson is associated with the Higgs field. Peter Higgs theorized that right after the Big Bang, the Higgs field spread out all across the universe. Any particle that would interact with the field would get an associated mass. The more the particle interacts, the more massive it is. Conversely, less interaction leads to a less massive particle. [3] This particle, if found, would balance the massive W and Z bosons.

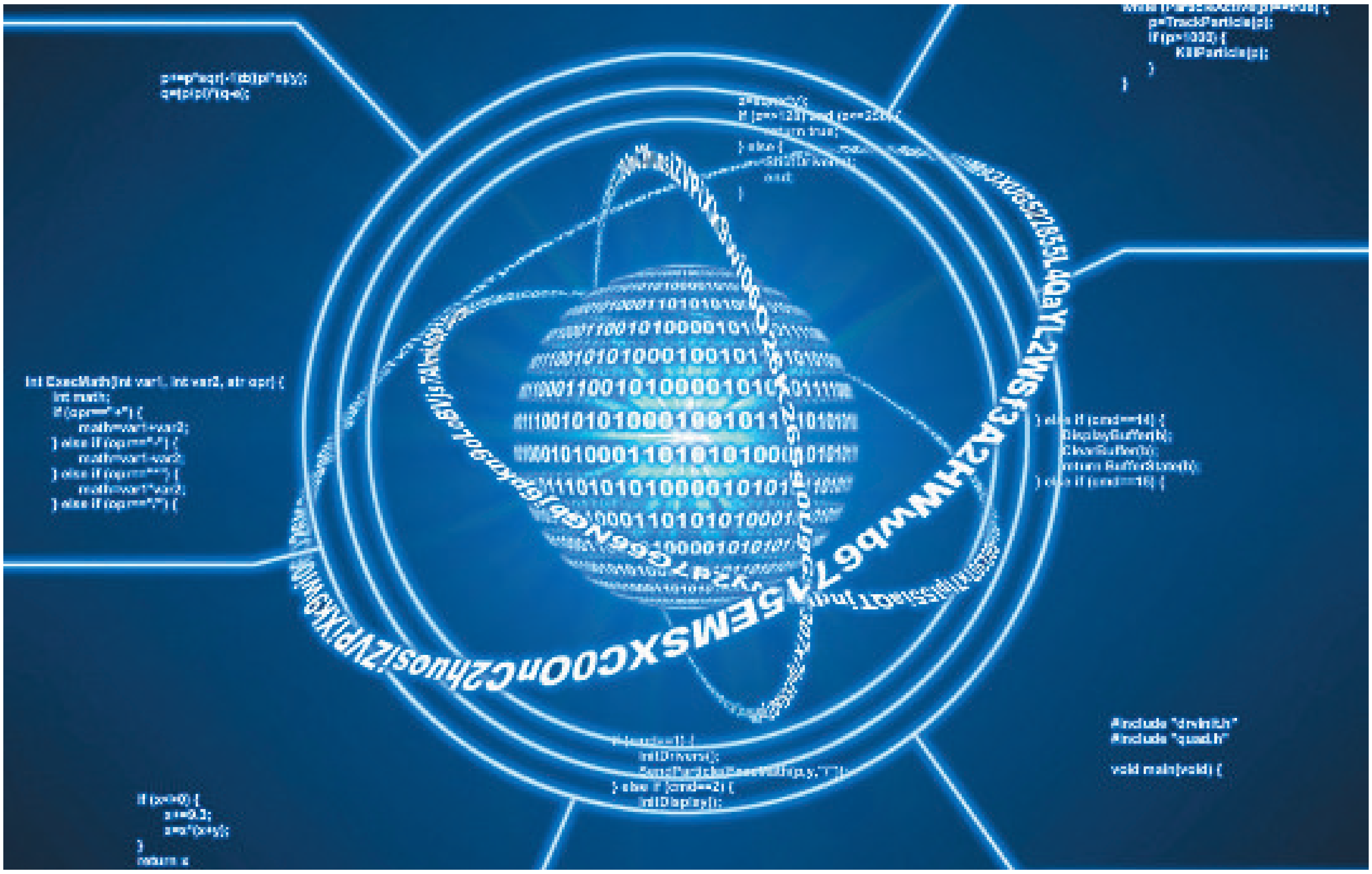
The Higgs boson, as the name indicates, is a boson particle. It has no spin, no electric charge, and no color charge. It gives other particles their mass through the Higgs mechanism and decays almost immediately. At a certain energy level, the electroweak force is spontaneously distorted and the Higgs mechanism is triggered. In this process, the bosons have no mass. The bosons that move slowly through the Higgs Fields become massive while those that move through the field at high speeds become massless. This interaction with the field gives particles their mass. Unfortunately, the Higgs boson has yet to be officially discovered.

CERN, the European particle physics lab, in search of the Higgs boson, has constructed the largest collider in the world. A collider is a particle accelerator that smashes particles of similar mass and kinetic energy in head-on collisions. These particles travel at extremely high energy and at speeds close to the speed of light. Their collisions produce other particles. The Large Hadron Collider (LHC) provides proton-proton collisions with a center of mass energy of 14 TeV. [2] Recently, in July 2012, CERN made an announcement that two independent experiments have collected extremely similar data on a particle that fits the description of the Higgs boson. The mass of the particle is said to be about 125 GeT/c2, with a very high level of significance. Currently, while physicists are very cautious about making an official annoucement of discovery, most have said that the collected data concurs with the theorized Higgs boson of the Standard Model.

Finding the Higgs bosons would move physicists a step closer to finding a uniform theory that explains all the fundamental forces. "It will fill in a huge hole in the Standard Model that has existed for more than 50 years, according to experts."[3] If this particle is found, then the Standard Model is complete and people will have a better understanding of how the universe was formed. The discovery of the Higgs can lead to a more complete and accurate narrative of the first few moments of the big bang.

The Higgs boson would be the progenitor of every piece of matter, including humans. If discovered, it would be an incredible step forward for science and a major achievement for humanity. As physicists continue in their quest to confirm the discovery of the Higgs, they will attempt to continue to develop equations that further unify, within one theory, the physical mechanisms of the universe. Although no immediate impact of the Higgs boson is felt by everyday society, it is still a mystery that physicists are determined to solve. The story of the Higgs boson continues to unfold. ■

Tasneem Hossain *is an avid student of physics.*



Quantum Computing

Today we are in the age of computers. Almost everyone has personal digital devices ranging from cell phones to tablets which allow them to take computing power with them everywhere they go. An amazing aspect is that computer technology can get even better and faster. Current machines compute linearly, which means that computers function in a linear, step-by-step fashion. The progress of these linear computers was modeled as Moore's law. This law states that the number of transistors on a central processing unit (CPU) doubles every two years. [1]

Transistors are used inside computers for computations. The number of transistors a computer possesses has a direct relationship to the processing speed of the computer. This would imply that computer speeds double at about the same rate as the number of transistors on CPUs. In order to achieve more processing power on CPUs, transistors need to become more and more microscopic. Due to the microscopic scale of transistors needed to keep up with Moore's law, however, it would seem that the limit of Moore's law will be reached very soon. [1]

With quantum computing, on the other hand, tasks are not completed linearly. This means that the amount of processing power is not determined by the number of resistors — resistors, as the name suggests, impart resistance to the system to regulate the flow of current. The processing power of quantum computers increases exponentially with every additional unit of information. While possessing the same amount of bits a classical computer would use, quantum computers can be incredibly fast because they perform simultaneous calculations. The strides that have been made in the field of quantum mechanics and particle physics have helped the development of quantum computers.

While possessing the same amount of bits a classical computer would use, quantum computers can be incredibly fast because they perform simultaneous calculations.

The idea of a quantum computer was first posited in the 1980s by physicist Richard Feynman. [2] Feynman's work in the field of particle physics and quantum mechanics led him to propose the idea of a universal quantum simulator, or a quantum computer. These types of computers use principles of quantum mechanics to their advantage. Quantum mechanics looks at the nature and behavior of microscopic particles. [3] As quantum computers use particles on the microscopic scale, they are therefore subject to the laws of quantum mechanics. Unlike classical computers that use bits, which are the smallest units of information on a machine and, following a binary system are either a one (1) or a zero (0), a quantum computer uses quantum bits also known as qubits that can be either a 1, a 0, or both simultaneously. [2]

A qubit is a 2-state quantum system that can exist in any of its two states or in a superposition of both states. For example, the electron of a hydrogen atom can exist in several different states: its ground state, excited state, or a superposition of the two. The state of the electron can be measured, resulting in either a 1 or a 0 defining the electron so that it is not in a superposition. [4] As per quantum theory, the very process of measuring itself can determine the obtained result of the measurement. The probability of the outcome resulting in a 1 or a 0 can be determined by measuring the system. Once the system has been measured, it is permanently in that state and further measurements will not change it.

When there are two qubits in a system, the measurement of these qubits can become dependent on each other. When this happens the qubits are said to be entangled. [4] This means that the state of the qubits cannot be determined separately and that the measurement of one qubit affects that of the second qubit. The four different states of the two qubits can be written as 00, 01, 10, or 11 and can present in any superposition of the four. When two qubits are entangled the states are 00 and 11. By measuring the first qubit, the state of the second qubit can be determined. [5]

Quantum computers use quantum algorithms to solve problems. As quantum algorithms perform steps in a non-linear fashion, they are much faster than the algorithms used on current computers. One example of a quantum algorithm that is not only faster but more efficient is Shor's Algorithm for Quantum Factorization. Shor's Algorithm takes advantage of qubits and their superposition to find the prime factorization of a number. [6] It is important to note, however, that not all algorithms are faster when computed by a quantum computer. This is because, in order for an algorithm to be faster, it needs to be in a process that utilizes implicit determination. [7] This means that the algorithm needs to utilize the states of the quantum computer.

A quantum computer is not without faults. One fault is the result of interactions between the system and its environment. One such phenomena is called decoherence. [8] In a quantum system, decoherence can be seen as a loss of information into the environment. This is a problem because lost information leads to incorrect results. Quantum error correction is a field that is expanding to help solve this issue. [9] Another problem is the usefulness of a quantum computer. The question of what they will be used for often arises. While they can be utilized to perform fast calculations and database searches, the commercial value of quantum computers is uncertain. [10] However, that is not to suggest that quantum computers would be entirely useless. Since quantum computers have not been commissioned for large commercial purposes, it is uncertain what they would be employed for in mass markets.

Since quantum computers have not been commissioned for large commercial purposes, it is uncertain what they would be employed for in mass markets.

One example of a new technology being used for quantum computers is quantum dots. Quantum dots allow quantum information to be relayed through a computing device analogous to a qubit. One of the latest discoveries is from Princeton University where they are using indium arsenide as the material to fabricate quantum dot structures. [11] They chose to utilize this material due to the its ability to hold qubits and to analyze them. This discovery could allow researchers to control millions of quantum bits.

The future of computing, it appears, lies in the quantum world. People want faster, newer machines that can do more than what current computers are capable of. As such, research about quantum computers is ongoing and progress is being made. The next generation of computing machines will arrive thanks to quantum mechanics and the related new technologies which could enable the fastest computations. There is still a long road ahead to solve the current problems of quantum computers and find efficient ways to measure and control qubits. However, there is no doubt that these machines will come about and bring great new innovations. ■

***Walter L. Church IV** is a sophomore studying computer engineering.*

Water or an Anomaly?

What's the big deal about water anyway? Scientists always bring up this compound when debating the possibility of life on other celestial bodies. Your parents probably suggested you drink a bottle of water instead of a sugary drink. Why does it matter? It's a clear, almost tasteless liquid that covers 70% of the Earth. It's one of the most prevalent liquids on the planet. Any given organism's weight is roughly 70% water. [1] It is recommended that the average person consume 64 fluid ounces of water every day. In fact, one can only survive a couple days without this liquid. [2] Water is an odd molecule. "Without water, it is all just chemistry, but add water and you get biology." [3]

Water possesses many unique properties known as anomalies, and these strange qualities set water apart from other liquids found on Earth.

Even though water is such an integral component of life and one of the most ubiquitous liquids on Earth, scientists have just started to investigate and discover more mechanical components and applications of water by utilizing recently developed knowledge of quantum mechanics and particle physics. One question, it seems, of utmost interest is, "What makes water so special that humans cannot live without it?" Another question is, "How can water be utilized to successfully navigate the challenges humanity faces in the 21st century?"

Water possesses many unique properties known as anomalies, and these strange qualities set water apart from other liquids found on Earth. One important reason these anomalies occur is due to the chemical elements which constitute water. Most people know that water is made up of one oxygen atom covalently bonded to two hydrogen atoms. Multiple water molecules in turn connect to each other through hydrogen bonds. This seemingly simple fact conceals the reasons for most of water's anomalies.

The hydrogen and oxygen atoms in a water molecule are held together by polar covalent bonds; the H and O atoms share electrons unequally. This polar molecular force causes, at the intermolecular level, electrostatic attractions between the slightly negative oxygen atom and the slightly positive hydrogen atom. These attractive forces are called hydrogen bonds. Hydrogen bonds explain the interesting phenomena regarding the density of ice and the high specific heat of water. As the temperature of water drops and water enters its solid state, it becomes less dense, because hydrogen bonds between water molecules spread out the molecules when freezing temperatures are reached. [4] This defies the “convention” of the density relationship of solid and liquid phases of most compounds. [3] Because ice is less dense than liquid water, only the surface of water will freeze. This property of water enables the preservation of marine life in winter weather since it prevents the entire body of water from transforming into ice. [3]

Also, hydrogen bonds are fairly sturdy and break only after a large addition of thermal energy. [5] Only after these bonds are broken can the kinetic energy of water molecules increase. This explains the high specific heat of water. Because water requires a large gain or loss of energy to change its temperature, this occurrence provides marine life time to adjust to climatic swings which may prove to be very useful with the issue of drastic climate change.

Another fairly recent discovery that further elucidates water’s unique properties is the correlation between quantum energy states and the chemical makeup of water.

This particular chemical perspective of understanding the anomalies of water has been accepted within the scientific community for quite some time. While attempting to determine the exact density for water, researchers discovered “heavy water.” [7] The term “heavy water” refers to the molecule D_2O where, in place of the standard hydrogen molecule, there exists a molecule of the hydrogen isotope deuterium. The differences between “light” water and heavy water (deuterium has one neutron instead of the more common hydrogen isotope which has none) further demonstrates the important role hydrogen bonds play in water’s abnormalities. [8]

Heavy water, which is found in natural water sources, “behave[s] more like classical, as opposed to quantum objects....” Allan Sopher of Rutherford Appleton Lab proposes that “the properties of water are affected” by the length of their hydrogen bonds. [8] The hydrogen bonds binding deuterium with oxygen are “4% longer” than the bonds between hydrogen and oxygen. [8] These unique properties make heavy water a tool to learn more about various biophysical processes such as protein synthesis and metabolic rates.

How do the anomalies of water relate to biophysics and other functions of humans? Many actions of biomolecules, such as proteins and nucleic acids, require an aqueous environment in order to function. [1] Water helps amino acids perform different actions based on their physical shape by helping the acids curl into their proper form. [3] Water sends messages to proteins about incoming DNA. [3] Proteins cannot physically connect a DNA molecule with too much saturation, and research shows that water saturates imperfect DNA molecules.[3]

On the cellular level, water clears cells of “metabolic” residue. [1] Cells communicate using water, and nutrients are transported from cell to cell through water. [1] In order to maintain the pH of blood at 7.3, cells use water’s ability to dissociate into hydrogen ions and hydroxide ions by sending hydrogen ions across membranes. [9]

In an experiment using Nafion, “a proton-exchange membrane used in fuel cells,” scientists discovered that the protons in the water confined in the membrane had double the kinetic energy of “bulk water.” [10] The distances used in the experiment are “roughly equal to the distances within biological cells” and the data calculated provide a clue to how the quantum mechanics of protons play a role in cellular life. [10]

Another fairly recent discovery that further elucidates water’s unique properties is the correlation between quantum energy states and the chemical makeup of water. Zero-point vibrations—the lowest energy state a quantum mechanical system can have—are “a product of the impossibility of pinning down the total energy of a system with absolute precision at any given moment in time.” [3]

The zero-point motion of the hydrogen and oxygen atoms determines the volume of ice and causes ice crystals to stop shrinking before a temperature of absolute zero. [11] This allows water to bond with other molecules smoothly. [3] This property of hydrogen bonds and zero-point vibrations gives water the moniker of the "universal solvent." [12] Water dissolves a substance by pulling it apart ion by ion. [4]

Other recently discovered qualities of water are also helping fuel new technologies that will address many modern concerns such as clean energy and improving life expectancy. In the race to acquire methods of attaining cleaner reusable fuels, scientists are looking at water as the key to a promising, relatively new category of fuels — hydrogen fuels. Hydrogen is a cheaper, cleaner reusable fuel. The challenge, however, has been to find an efficient way to split water molecules to generate hydrogen. [13] Rather than using heat or electricity, which utilizes more energy than is produced, researchers at Penn State and Virginia Commonwealth University have discovered that utilizing the geometry of "clusters of aluminum atoms" can split water molecules at room temperature. [13] They hope to continue refining their methods so that they can usher in the age of hydrogen fuel.

Another avenue where research on water and biophysics is ushering in exciting new technologies is the field of cryogenics. Cryogenics is the field of science interested in the process of extreme cooling and observing how materials react at extremely cold temperatures. Researchers at Rebirth, a cryogenics research facility in Germany, are finding new improved methods of preserving transplant organs. Another ongoing long-term project at Rebirth is to develop a process through which humans who are frozen at death could be reanimated by—in a nut-shell—defrosting. [14]

As facts do reveal, there is more to that simple glass of water than one would assume. Water maintains life on Earth and enables numerous functions in the human body. Perhaps, in our lifetime, scientists will discover a way to create clean fuel using the H_2O molecule. Maybe one should think twice before dismissing water as just a humble liquid. ■

Gabrielle Rejouis *is a freshman history major. She has written for her high-school yearbook, and expects to keep writing for the rest of her life.*

Frontiers of Power Transmission

Power is an essential part of modern life. Hospitals, offices, and homes depend on it for their machines, data, and lifestyles. For the average person, losing power can be frustrating, but for institutions, such as hospitals, it can be debilitating and costly. Hospitals might be required to relocate patients elsewhere, and businesses may lose information and productivity. The technological era shows no signs of slowing down as consumer demand and reliance continually increase. As such, there is an obvious need for improvements in energy usage. One of the best ways to accomplish this is to waste less energy. With power needed to fuel the future, improving power transmission methods is an excellent way to initiate advancements. Research in particle physics could provide the means to achieve this by offering new solutions.

Since a great deal of energy is lost in the process of transporting power, the method of delivery is one major area ripe for improvement.

In order for electricity to be used by people, large amounts of power are transported over vast distances using electrical grids. The power supply is generated as needed. Should the demand for energy be greater than the supply within the confines of a particular grid, a different grid can act as a backup so that an overload does not occur. Also, energy is often bought from a location farther away because it is less expensive than locally produced energy. In the first step of most power transmission systems, electricity is created from fossil fuels or other non-renewable sources. This electricity is then passed through high-voltage transmission lines which, over long distances, results in some loss of energy. The current then reaches a transformer, which lowers the voltage so that the power is able to get to its final destination at a safe level.

Since a great deal of energy is lost in the process of transporting power, the method of delivery is one major area ripe for improvement. With the existing need to conserve power for future use, "modernization of electric power systems…will be key to improving the standard of living of future generations." [1] This is especially evident in cities where existing copper transmission lines are already near full capacity. Since metropolises seem to only continue to expand, this positive progress in transmission of energy is urgently needed.

Current power transmission lines have line losses, which are losses that occur during transmission through wires also known as conductors. Manifesting as heat, these losses, of about 7%, are due to resistance from copper or aluminum conductors. [2] The goal of modern scientists and engineers then is to change the transmission system to reduce the losses. But this must be done while meeting the demands of current electrical operations and maintaining low costs.

The amount of power that is successfully transmitted is dependent on various factors including voltage, conductors used, and the resistance of the system. Current is the electron flow while the voltage is the energy needed to move the current. Power is the rate at which energy is transmitted. Ideally, the voltage should be increased and the current kept low in order to ensure greater efficiency. Conductors are used to promote the flow of electrons while resistance works against the current. Since all of these affect the amount of current, they directly impact the power transmitted.

One good aspect of the existing system is that high-voltage lines are used instead of low-voltage lines, because "line losses decrease with increasing voltage." [3] This is due to the relationship: power is equal to current times voltage. The greater the voltage and the lower the current, the lower the resistance through the conductors. Hence, the loss of power is minimized. Particle physics research would improve these factors and help make power transmission more efficient. Since power is in high demand at present, and that demand will only continue to increase in the future, as populations, global standards of living and resultant consumptions increase, decreasing power losses is of prime importance. The need for improvement is even more evident considering that "power transmission is less efficient at times of higher demand," because the increase in transmission creates a surge in flow of current which means more power is lost. [3]

Since a good conductor is vital to efficient power delivery, one other specific area for improvement within power transmission is the material of conductors used. Existing power systems typically use conductors of copper or aluminum which boast benefits of "reasonably high conductivity, low cost, and chemical stability." [1] The ideal conductor must be able to fulfill these criteria and work in the real world, which implies working under various conditions. Superconductors are a type of conductor at the forefront of power transmission technology since these can transport five to ten times the current that copper or aluminum cables can. [4] They "allow current to flow with essentially zero loss." [3] This would greatly benefit power companies by conserving energy overall while supplying electricity to consumers.

In a superconductor, the electrons pair up when carrying the current. Normally, electrons repel each other because they have the same charge. But particle physics allows this pairing to occur because the "electrons in a superconductor must occupy a quantum-mechanical state distinct from that of normal conduction electrons." [5] While this process is not fully understood currently, this change in state is thought to be due to the electrons indirectly becoming attracted to other electrons by creating vibrations in the atoms. With this attraction, the electrons become paired up and this increases stability. The pairs of electrons "move (together) without hindrance" and are "oblivious to other electrons" that are also moving. [5] Therefore, the superconductors conduct electricity with zero resistance, which in turn means zero power loss.

While superconductors may seem like the perfect conductor choice, several factors prevent a complete transition in the near future. Cost, for one, is a major factor for companies. Any change is expensive in power transmission since so many areas, including product development, replacement, and maintenance, are affected. The companies' ultimate goal is to cut costs associated with power loss in the systems currently in place. Switching to superconductors means high initial and maintenance costs. However, in time, the savings from not losing energy during transmission could equal or surpass the cost incurred due to the change.

Another issue is that, typically, superconductors work best at low temperatures. If the superconductor heats up, then the electrons no longer travel in pairs, so the conductor would behave as a normal conductor. Research, however, has led to the development of high temperature superconductors (HTS) which work by using liquid nitrogen for cooling. Though the way the HTS works is not yet fully understood, they seem to be the best bet for better electricity transmission. So, while the implementation of superconductors is "technically feasible," it is not yet economically sound on a large scale. However, it may be an option for the future. [1]

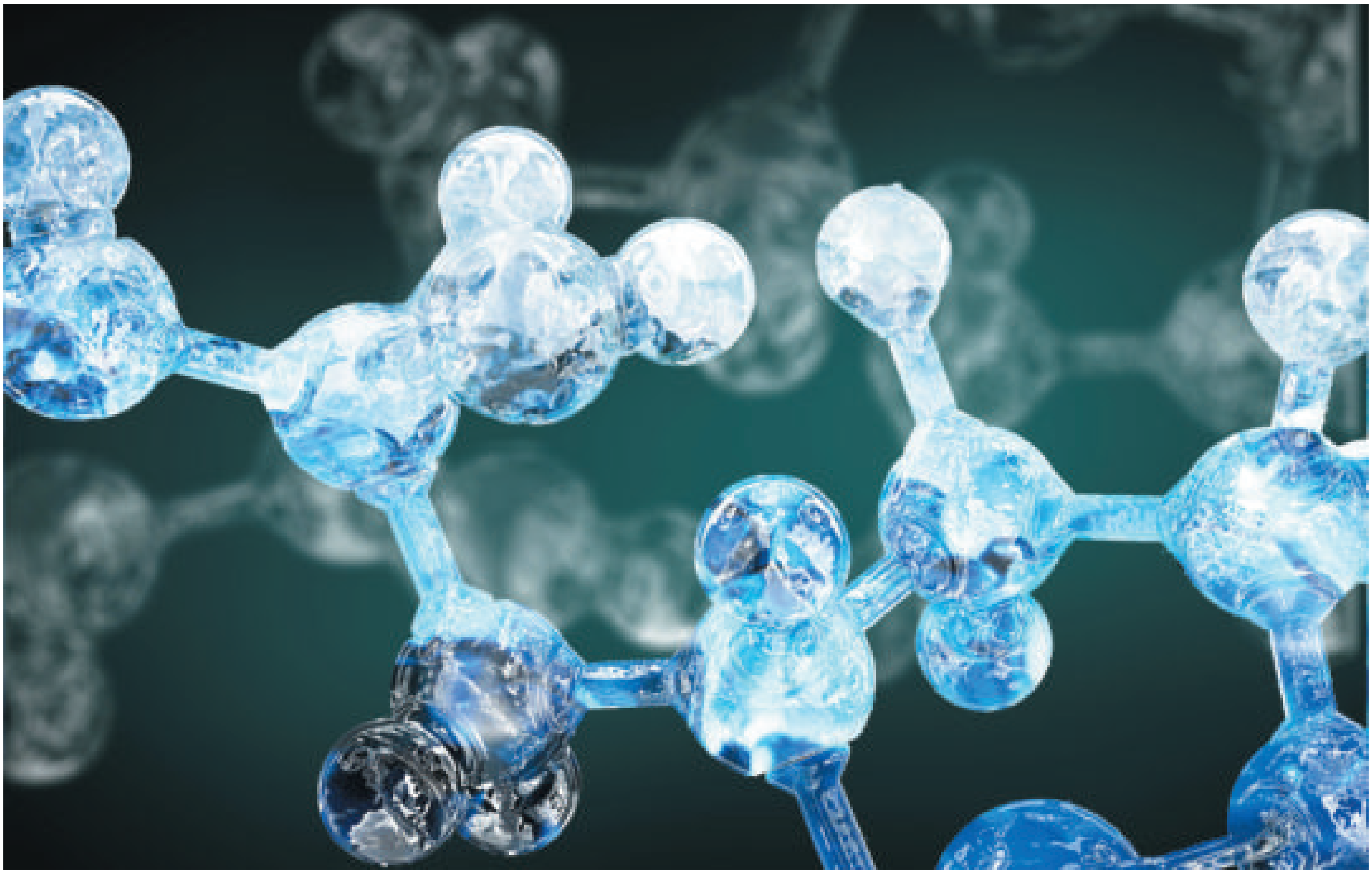
The U.S. Department of Energy has provided about $29 million of funding for the longest superconducting cable system used for power transmission in the U.S. [6] Made by the company, American Superconductor, and spanning about a half-mile long section of the Long Island Power Grid, this system is a working component of the electrical system. The company has since received further funding from the U.S. Department of Homeland Security to protect the impressive grid. Other similar projects have been planned for California, Germany, and Japan. [6]

The new systems are more reliable and lower in resistance which means losses will be lower. The improvement also reduces grid congestion so that the system is not overloaded in times of high demand. In case of an electrical problem, the system also "switches from being a very low resistance wire to being extremely high resistance, just by the nature of…the wire itself." [6] This helps to prevent electrical failures. As of now, this is still an emerging area of application for superconductors. [7] If the issues of practicality and cost are addressed, this could be a viable course for energy programs.

Innovations from research in particle physics combined with regular maintenance of transmission systems are vital in developing better electricity delivery. Research about superconductivity that can be applied to power transmission is being funded and could, potentially, lead to breakthroughs in this field in the near future. Greater understanding about the movement of electrons in superconductors is needed. A more in-depth analysis may spur further progress. If the cost is acceptable, then implementation will occur and efficiency can be improved. Power needs and the desire to be energy efficient will continue to increase. Particle physics may hold the answer to meeting the energy challenges of the 21st century. ■

Jennifer M. Ligo *is a sophomore majoring in chemical engineering at NJIT.*

Long Island American Superconductor power grid.



Particle Physics & Biomedicine

For as long as we can remember, the fields of biology and physics have been viewed as opposites. Physicists viewed biology as a science devoted to mere classification, while many biologists viewed physics as an incomprehensive subject dealing mostly with theories that are not applicable to everyday life. However, in this era, physics and biology are becoming more intertwined than ever before. The discoveries of DNA, cellular chemistry, and the principles of inheritance have generated a need for new tools and technologies. This demand has, in turn, created a mutual appreciation between the two fields which is generating a wealth of exciting research on many new frontiers.

Particle physics is the latest branch of physics to capture the attention of the scientific community. Surprisingly, this seemingly complex division of physics simply deals with matter, the basic building block of the universe. To be more precise, particle physics deals with the existence, relationships, and interactions of subatomic particles that make up both radiation and matter. Physicists have been working on reducing the universe to its most elementary units for centuries and recently progress has been made. We have known about atoms, protons, neutrons, and electrons for years and recently we have learned about quarks and leptons. With new discoveries from the Large Hadron Collider in Geneva, Switzerland, scientists have also been able to learn about various forces that act upon matter. [1] As generations of research are being compiled together, there are an increasing number of practical applications developing from particle physics relating to biology, among many other fields.

One of the main uses of particle physics in the field of biology is x-ray crystallography, which uses particle physics to determine how atoms are arranged in a crystal. In brief, a beam of x-rays strikes a crystal, which causes beams of light to spread into many directions. [2] With the various angles and intensities formed from the diffracted beams, a physicist or, specifically, a crystallographer can make three dimensional models of the electron densities within the crystal. With this model, the arrangement of the atoms in the crystal can be determined, along with other structural aspects such as how the atoms are bonded. When one thinks of crystals, the image of a diamond or something similar usually comes to mind but it is a misconception to think that all crystals are diamonds. A crystal is simply a material which is made up of ions, atoms, or molecules in an ordered pattern. In fact, many organic and biological molecules are formed from crystalline patterns. [3] Hence, x-ray crystallography can be useful in determining the structure and functions of substances such as vitamins, drugs, proteins, and nucleic acids like DNA. Once scientists determine structures of different proteins or research the various chemical interactions and processes in a biological molecule, they can begin to design pharmaceutical drugs to be used to cure specific diseases.

After physicists use x-ray crystallography to model a particular molecule, they submit the information they learned about the structure into various databases. There are many important crystallographic databases. The Cambridge Structural Database is used for small molecules, while data concerning inorganic compounds and molecules are stored in the Inorganic Crystal Structure Database (ICSD). These databases are very important for chemists, but the database which is most useful for biologists is the Protein Data Bank (PDB) which stores a wealth of information about protein structures. The data in this depository bank is obtained through the aforementioned x-ray crystallography technique or by other spectroscopy methods such as magnetic resonance imaging (MRI) which utilizes the radioactive phenomena of nuclear magnetic resonance (NMR).

This Protein Data Bank is freely accessible via the internet to anyone who is interested in its information. Biologists, biochemists, and pharmacists all over the world gain access to the data within this bank and glean information about their respective fields. On an important side note, most data regarding these structures obtained for private medical and pharmaceutical companies are not deposited in public databases. However, nowadays, more and more scientific journals and funding agencies are requiring scientists to immediately place their data into the PDB so that it is available to the public.

This Protein Data Bank is freely accessible via the internet to anyone who is interested in its information.

To summarize thus far, various applications of particle physics technologies, such as x-ray crystallography, are used to decipher the structures of different proteins and other biological molecules. This information about the structures is then stored in online databases so that scientists and pharmacists across the world can access them. The information in these databases about the structure of proteins is key to understanding important biological processes. Eventually this information can lead scientists to find cures for diseases. for instance, understanding protein structure allows for the development of more effective drugs.

Once the structure of a protein has been discovered, pharmacists then have to identify inhibitors or activators of that specific protein, depending on the protein, so that the protein's activity can be decreased or increased. Most drug molecules are protein inhibitors so they bind to specific proteins and decrease their activity. These drug molecules are judged by two characteristics, specificity and dissociation constant. Specificity is the lack of binding to other proteins and the dissociation constant is the concentration of the drug which is needed to inhibit the protein. A high specificity level and a high potency ensure that the new drug will have a low toxicity level and therefore will have little to no side effects on the patient. [4]

One such drug which was developed with the aid of x-ray crystallography and particle physics was Lopinavir/Ritonavir which is commonly known as Kaletra. Kaletra is the world's most prescribed drug to fight HIV infections. Lopinavir/Ritonavir is an example of the type of drug molecule previously described that binds to a specific protein and inhibits its activity. This drug was discovered in Abbott Laboratories, one of the earliest users of x-ray crystallography for developing medicines. Using this newfound technology, researchers found points of attack of the HIV protease inhibitors. [5] That is, researchers found a means to prevent the HIV viruses from creating more replicas of viral proteins. This discovery led to the development of Lopinavir/Ritonavir.

Kaletra is but one example of how technology based on the principle of particle physics led to the development of more effective drugs. As advances in x-ray crystallography occur, applications of particle physics principles are enhanced and are becoming the norm for how new discoveries are made in biomedicine and drug development. In the past, particle physics was viewed largely as just a theoretical field with no potential applications. However, since the first cyclotron was installed in Berkeley, California, more and more powerful accelerators are being built. These new accelerators, such as the Large Hadron Collider at CERN, are encouraging the development of useful new applications, not just in medicine, but also in computer science, national security and other industries. ■

Abhishek Trivedi *is a biomedical engineering sophomore focusing on the field of tissue engineering.*

An Interview with Frank Wilczek

Frank Wilczek is an eminent physicist who has been recognized for his work in physics with many awards including the 2004 Nobel Prize in physics. His work has led to many important new frontiers for physics including the discovery of asymptotic freedom, the invention of axions, and the exploration of new kinds of quantum statistics. He has also authored several books including *Longing for the Harmonies* and *Fantastic Realities*. Frank resides in Massachusetts with his family. He is the Herman Feshbach Professor of Physics at MIT. [1]

1. In your book,* Fantastic Realities*, you mentioned that mathematics and philosophy were your initial interests. Why did you ultimately choose to make your main interest physics?

What I liked to do was think mathematically and to learn things. But I really wanted to understand things about the world as opposed to pure thought. So I didn't want to do pure mathematics. But I really liked mathematics. I was like a hammer in search of a nail. I acquired a sort of toolkit of technique and I really enjoyed that, but I wanted to use it for something. I was in that state when I went to Princeton as a graduate student in the math department.

I had earlier, in my undergraduate days, explored philosophy and neurobiology. The kind of philosophy I was interested in, mathematical logic and analytic philosophy, was kind of over in a way. I felt it had produced some very important insights and attitudes but the cream had clearly been taken off the milk.

In neurobiology, I rapidly convinced myself that it wasn't really ready for mathematical treatment. It was like where physics was in the 6th century. I think it is very exciting now but at that time it was premature for mathematical treatment. Now, it's very promising indeed.

So anyway, I didn't know what I wanted to do and I just went to Princeton and studied more mathematics. However, I was looking around, wandering over to other departments and reading very widely in other subjects to see what was promising. Fortunately for me, in retrospect, the math department was right next to the physics department. So it was very easy to wander over there. I went to seminars and colloquia and I got a sense of what was going on. I very quickly discovered that very exciting things were happening in physics at that time. And that's what happened and I never looked back.

2. How would you say your training in philosophy has influenced your study of physics? Is there any particular instance when this discipline helped your research in physics?

The philosophy of the last century became very interested in the foundations of mathematics and logic. That turns out to be essentially the same and certainly very, very closely related to computer science. How do you actually calculate things? What does it mean to do mathematics? What is the bottom line so to speak? So the logic that I learned made it much easier to use computers in creative ways.

Another thing was my early religious training. It taught me to think big when you're surveying a body of knowledge or an area of interest, to not think of it as a settled thing but to look for weak points, analyze concepts critically, and think about how it might be better. So thinking big and thinking critically, that's what you can take from philosophy. Most of the actual things philosophers said are nonsensical.

3. Could you tell us about the research you conducted for which you were awarded the Nobel Prize and the significance it has for the average person?

It can be described at many different levels. Fundamental physics is about describing the way matter behaves, the way the universe behaves. We've learned that a very fruitful way to do that is to understand thoroughly the smallest bits of matter and how they interact in a precise way because everything else is kind of just adding it up. The laws act locally. They only act on a few bodies at each time. It's complicated when you come to chemistry but in some sense the base of it all is understanding the fundamentals.

And that has turned out to be an amazingly successful program and we've discovered that you can analyze the world in terms of just a few forces and a few basic building blocks. According to our modern understanding, we have a very accurate account of matter based on there being four forces. Two of them are kind of classic forces, gravity and electromagnetism, which have long standing theories. Gravity [which is modeled by] Newton's beautiful equations from the 17th century, and then we had general relativity, which improves the theory enormously in profound ways in the early 20th century. Electromagnetism matured in the 19th century with Maxwell's equations—all that was blocked by quantum mechanics. The foundations were sort of rearranged but amazingly, the basic forces still survived all that. The framework changed but the laws didn't in some sense.

The other thing that happened in the early 20th century on the experimental side was that people discovered the atomic structure of matter. Atoms are constructed of electrons bound to tiny nuclei in the middle and governed basically by electromagnetic forces. That's what dominates atomic structure. And that was understood by about the 1930s.

The great question became to understand what this nucleus is, because this nucleus was completely mysterious.

The great question became to understand what this nucleus is, because this nucleus was completely mysterious. The nucleus is where all the mass and the positive charge of the atoms are. It doesn't make much difference for chemistry because the electrons are for chemistry. However, for many things such as the way the sun burns and for fundamental understanding, we wanted to learn how the nucleus works. But it was realized very early that just the forces that had been known and analyzed before, gravity and electromagnetism, weren't going to do the job of explaining atomic nuclei.

So it was discovered by a very complicated history, which I won't even attempt to review, that there are two new forces. The basic one is called strong force; it's responsible for holding the nuclei together. It's reasoned that they're so small that the force is very, very strong. Then there is the weak force which is weak [laughs]. It's important because it's responsible for certain kinds of radioactivity and things that can't happen otherwise.

So any way, the dominant part of physics in most of the 20th century was to figure out what these forces are. Are there simple building blocks on which these forces act simply? At the nuclear level of protons and neutrons, the forces seem very complicated and that was very frustrating for people looking for good equations. A description of these forces worthy of Maxwell's equations of electrodynamics or Newton's equations of gravity or Einstein's general relativity didn't come up to those standards. It was just a lot of rules of thumb and funny business.

Eventually people learned there were some clues derived from experiments about how these forces had to act. There was some indication that protons and neutrons might have smaller things inside that would have simpler forces, much simpler forces. These are called quarks.

In a nutshell, we figured out the equations for the strong force and how to use them to actually compute physical phenomena.

What we did was, on the basis of some very indirect but powerful experimental clues, propose definite equations for the basic force between quarks. As a consequence of those equations, one has not only force but extra particles called gluons which people didn't know about before. So that was part of setting up these equations, predicting new particles. We were able to propose equations, which are actually very much like Maxwell's equations but on steroids. Instead of one kind of charge you have three kinds of charges. So instead of electric charge you have red, white and blue color charges. But the equations are awkward, similar but generalized, more elaborate versions of Maxwell's equations.

We proposed those equations and argued why they could be and should be the right equations. We also showed how to experimentally test that they are the right equations. Again, because you're dealing with very, very small things, it's by no means straightforward to test out the ideas of what the forces are. You have to focus on just the right thing and so that's what we did.

In a nutshell, we figured out the equations for the strong force and how to use them to actually compute physical phenomena. All the developments in this area since have shown that we got the equations right. These equations opened a lot of doors. They made it possible to understand in detail what happens in high energy accelerators. So for instance, the recent discovery of the Higgs particle — that would have been completely impossible if we didn't understand what usually happens, so that when, once in a trillion times, something unusual happens, supposedly that's this Higgs particle that you can identify. If you're looking for a needle in a haystack, you need to understand hay very well!

And it turns out it's been very important to understanding cosmology. Before you had a theory of strong force, you had no idea how to compute or even make reasonable guesses about what happened in the early moments of the big bang. Particles were very, very close together and sort of compressed to nuclear or even sub-nuclear densities. Before you had a theory of a strong force, you had no idea how to compute or make reasonable guesses about what happened. People's ideas were all over the map. But this theory [we proposed] not only gave you definite equations but it turns out that those equations are easier to solve at high energy and higher density. So it opened up the whole idea of early universe cosmology. It made it simple instead of hopelessly complicated. It did this for the original problem of understanding atomic nuclei as well. Actually that problem is still very hard, but now we have at least firm foundations.

4. Your wife, Betsy Divine, has chronicled the experiences of winning a Nobel Prize. From reading that blog it seems that there are many festivities related to winning the Nobel Prize. As such, I was wondering if there was one particular moment or experience that was particularly vivid for you?

Surely the absolute high point is the moment when you walk up and you see the medal and the certificate from the king. I mean that's just extraordinary! This grand theater is all set up and we're all very dressed up and there is music and elaborate ritual. But then there's this moment when it all comes together. The trumpets play. It's just fantastic!

Another thing that made an impression on me is the dancing. There were some magnificent occasions involving dancing. That was new to me. You know, I'd never done it and to do it in a beautiful, fantastic setting with everyone dressed up like 19th century fairy tales — that was another thing that made a huge impression on me.

5. You mentioned the Higgs boson particle earlier. Could you explain how we can expand our knowledge of this particle? Do you think we are close to discovering the existence and properties of the Higgs boson?

It's a milestone. Since the mid-70s, we've had something called the Standard Model which is a theory of almost all the forces I mentioned before. It was really formulated in its modern form in the mid-70s. It's gone from triumph to triumph over the last 30 years. One after another, the different facets have been tested and verified, except for one. The last major piece of the Standard Model that hadn't been tested directly was that it needed this Higgs boson. So it was a great triumph that this last piece of the picture, that has been so successful otherwise, appeared.

Let me step back to tell you why this particle is important. So, in a way, it's more novel and basic than many other particles that are building blocks in the Standard Model. Let me make an analogy, suppose there was a race of intelligent fish and at some point they started to study physics to determine the laws of motion. At first there are lots of complicated laws because the laws of motion in water are very complicated and that's what they would observe.

But eventually, some genius or some combination of geniuses among the fish would get the idea that maybe you could have simpler laws—the things we call Newton's laws of motion—the basic mechanics and the reason that the observed motions look more complicated you would guess is that there is a medium that sort of shoves the fish around. So the basic laws could be simple but nevertheless produce the observed phenomena if you had this medium, which complicates it. And that's exactly what happened in 20th century physics among humans. We realized that we could get spectacular equations, which in a way appeared too good for this world, if we assume that the world was full of some material that complicated their manifestations. That material is called the Higgs field because Peter Higgs is a lucky guy. It's a memorable name.

The properties needed of this material were pretty simple. It interacts with all the other components of the Standard Model. It has to be very rigidly determined by theory but in a mathematically simple way. And the consequences of those equations you get that way have been verified for many decades now. Many Nobel Prizes were given out for aspects of that: the discovery of the W Z bosons, the form of the neutral current in the interactions, the whole modern idea of weak interactions has in its center some assumptions of this medium.

So all self-respecting theoretical physicists suspected that there is this medium but we didn't know, until recently, for sure what it is made of. We know what it is not made out of. It's not made out of any of the other particles we had discovered. It's not made of quarks. It's not made of gluons. Those don't have the right properties. But the equations suggested that a simple possibility for what they're made of and that would be a single kind of new particle. You could say things about it. It would have to be electrically neutral and spin zero, a boson. You could say how it interacted with matter. You could say everything about it, it turns out, except for its mass.

So if you made the simplest possible guess for what this material might be made out of, the mathematically simplest hypothesis, you were led to discover the existence of a new particle, one particle that interacted in very predictable ways. The only thing that wasn't predictable was its mass. And that's what is called the Higgs particle. And now something has been observed that seems to have all the right properties. So you can measure how it's produced, how likely it is to be produced, [and] how likely it is to decay in several different ways.

So the equations of the Standard Model in their minimal form allow you to predict those things. How often do they happen? How often do different decays occur? All you need to know is the mass of the particle and you can check if it's consistent with all these other expected properties. So far what they're observing at CERN at the LHC seems to fit like a glove.

Let me emphasize, in a sense this was the physics of the 1960s. The equations have been in place for a long time. So really many of us are hoping this is kind of closing out the Standard Model, dotting the i's and crossing the t's. But we have more ambitions such as unification of forces and some say it's possible from the LHC. I'm hoping that those are in the offering in the near future.

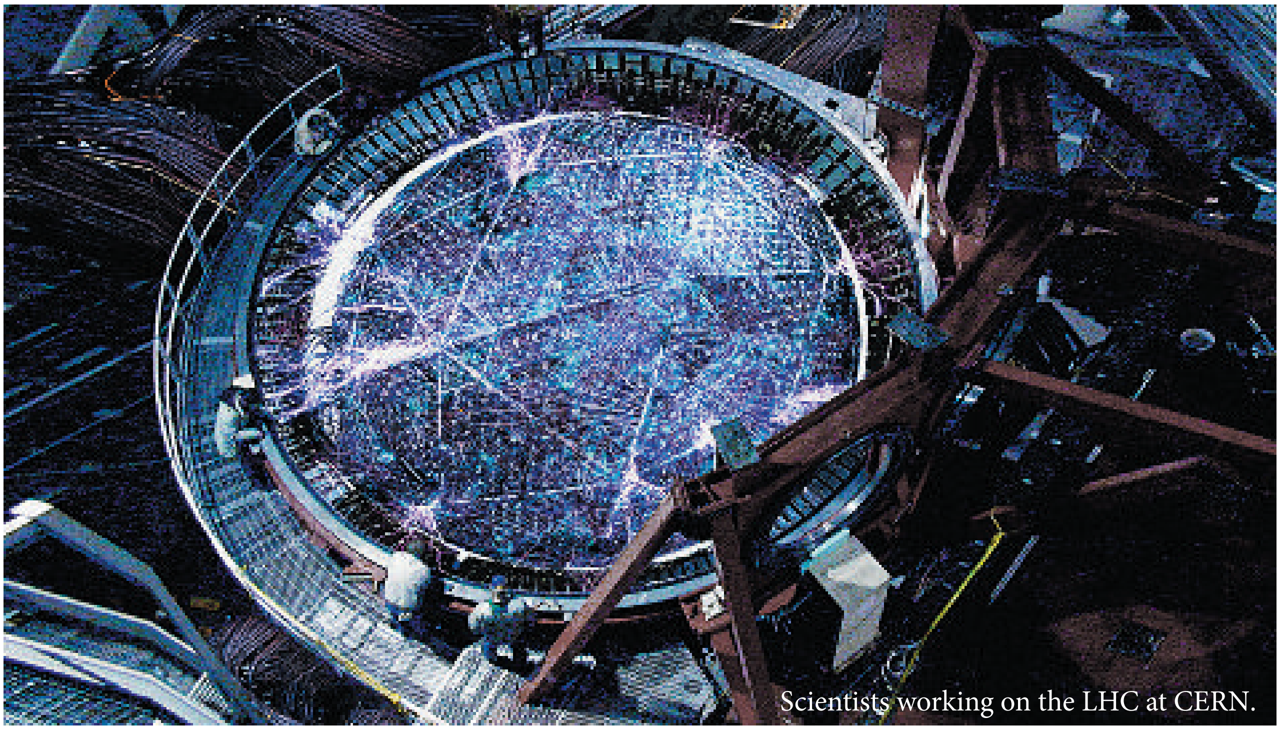
6. What level of understanding would you say we have in general with respect to black holes? How much more can we learn about them?

I think we have an excellent understanding of big black holes where it means anything with a mass larger then a small fraction of the nuclear mass. So anything formed from a stellar collapse or black holes at centers of the galaxies is in this class. We might be surprised by some startling experimental development but it would be a surprise if the equations that we have to describe big black holes—which are basic Einstein's general relativity and how matter interacts with electric fields that might be in black holes and the other matter that might be there - if those equations were invalid. Solving those equations is very challenging and observing their predictions and verifying them is very challenging from an experimental point of view. That will be a real adventure in the 21st century. But I would be very surprised if the fundamental equations need alterations, for big black holes.

Although it's kind of academic, there's a lot of theoretical interest in properties of small black holes. They have yet to be observed astrophysically, or at all really, because there are problems and even if you could produce them, they'd be very hard to see. But theoretically they're very interesting because we have two overarching theoretical frameworks in modern physics, quantum mechanics on the one hand and general relativity, a theory of dynamic space-time, on the other. If you combine those two, then the equations really break down at very short distances—basically quantum mechanics says that anything that can fluctuate does fluctuate and so any dynamical quantity like a particle has an uncertainty in position. So any dynamical entity fluctuates; general relativity says that space and time are dynamical and so it fluctuates. When you get down to very short distances, the fluctuation in, say, the distance between two points, the equations are out of here. We don't know how to deal with it. The whole structure of space-time seems to evaporate. So this is fascinating to theorists and there are a lot of semi-paradoxical thoughts. There's no consensus on even many basic questions.

I was shocked just recently. There's a hot debate among some very eminent physicists about whether the basic understanding of black holes, that I thought was settled for 50 years now, might be wrong. It's a question of if an observer falls into a big black hole, like a stellar one, whether they see anything dramatic or if they continuously go through the surface. The received wisdom for the last fifty years or so is that nothing passes through the event horizon. From the outside it's sort of dramatic since they lose contact with people, they sort of disappear. But as far as the actual observer, the equations tell you that, if it's a big black hole, that nothing particularly happens. They just fall through. Now, suddenly that's controversial. Some people have proposed that there is a fire. Try to fall through and take into account quantum corrections, you'll find that instead of just smoothly falling through and hardly noticing that anything's happened, you'll burn up.

So even very basic issues are still under debate. The problem with all that is physics is a discipline of experimentation. Also to me it's not as satisfying. It's purely an intellectual exercise. It doesn't have an application to reality in a tangible way. There are certainly fascinating intellectual issues. One motivation of thinking about them is we'd like to have a coherent view of the world and not have the equations break down. Another motivation is that sometimes thinking about matters of principle, even if they seem academic, it turns out that when you do them justice, face up to paradoxes, you learn things that do have consequences for more practical purposes or other missions that you might not have considered. General relativity for instance came out of worrying about the fact that gravitational mass is always equal to in-


Scientists working on the LHC at CERN.

ertial mass which you didn't have to think about. You could just say okay so that's what it is. But it was kind of mysterious. Einstein was very concerned with trying to do justice to that and this eventually led him to general relativity. All of that arose from that seemingly academic question.

Similarly, the problem of strong interactions was not the most surface problem of understanding atomic nuclei. A particular problem of quarks seeming to behave like free particles at short distances yet be confined at larger distances, so force grow weak at short distances and strong at long distances is very unusual for a force. It was worrying about this, not just unusual but actually a paradox, that led us to this theory. So sometimes thinking about paradoxes, it focuses your mind and can lead to fruitful unexpected consequences.

So to summarize, regarding big black holes, probably the equations are okay but even there people are raising questions like the fire wall issue. I would be very surprised if our understanding of a long time turns out to be not correct. But we'll see. The issues of principle when you think hard about small black holes arise and maybe they'll lead to insights that will ramify elsewhere.

Careful study of black holes might be a way to discover new particles that would be difficult to find otherwise.

Careful study of black holes might be a way to discover new particles that would be difficult to find otherwise. There is a particular particle, the axion that I introduced early in my career. The theoretical case for it has only gotten better over the years. The theory says it's very hard to observe and sure enough it is. It turns out that axions will form atmospheres around certain black holes and change the properties of those black holes compared to ones without axions. So a careful study of black holes might be a way to discover other particles. That would be fun.

One example is that helium was found in the atmosphere of the sun. It's hard to find on Earth because it's inert. It's hard to see its spectral line and there's not much of it. But in the sun, the energy is enough to spread it and make it visible. Sometimes astrophysical environments can be a way to find things that are otherwise hard to find.

7. Many sci-fi movies show earth being destroyed and humanity moving to other planets. Considering the idea that Earth will lose its ability to support terrestrial life, do you believe science will be able to prepare humanity for such an eventuality?

I guess I'm optimistic that humanity, broadly construed, will remain indefinitely. I'm less sure that there will be continuous progress, whatever that means. When I say humanity broadly construed, I say that with something very definite in mind. The human body is not built for space travel. It's very difficult to support human bodies in their natural form in those kinds of alien environments. I think the things you see in those sci-fi movies is totally absurd, you know people stepping out of their space ship on an alien planet. I always wonder where these people get their food.

So if you think of humanity as human thought, I think that could very well expand beyond the earth. I think there might be reasons to do that in the long run. You mightn't send bodies but you might send DNA. You might send computer chips with your thoughts. We might look into some kind of mechanical device that has more survival capabilities in alien environments. So if you mean by humanity, human culture and thought and achievements, I don't see any reason why that won't go on indefinitely.

Ten billion years from now there might be problems with the universe getting cold and dark but there's plenty of time till then. But I don't have the same optimism for the specific embodiment, the flesh and bone, of what we see around us today. I don't think that is the ultimate form that the cosmos is going to take.

The Borg from *Star Trek* is probably the way to go [laughs]. It's sinister, okay, but somehow I think that a distributed intelligence that doesn't necessarily take the form of individual operatives is what's going to happen.

8. In* Fantastic Realities *you wrote that students should read the works of previous masters of science. What three texts or three authors would you say have been indispensable for you personally?

You know it's been different at different stages of my career; different influences have played roles. Certainly one influence was Einstein's papers particularly on relativity, which really every student of physics should read because they're beautifully written. And they're short. That's another thing that is so striking, they're short [laughs]. They're not terribly dense with equations surprisingly. They deal with big ideas in an astonishing way. They really formed my writing style and style of thinking. Because it was sort of the stuff I was studying first. It sort of set the style that I followed ever since. I try to copy Einstein's papers in that my papers aren't cluttered with equations, they're short. They have a point and you say it and then shut up. So that's certainly one.

Then in college I came upon Dirac's book on quantum mechanics which is just gorgeous. It has a quite different, much more mathematical style but the details are handled so beautifully and at such a high level that it made me want to learn more about quantum mechanics. Also, influenced is not strong enough; it very much imprinted the way I think about quantum mechanics ever since. It covers very basic properties. I've really learned about in a physical, deep way from Dirac's book. In some way quantum mechanics and general relativity are in some tension in an area of fundamental law. So there wasn't much overlap between Einstein and Dirac technically. Those were the places I learned quantum mechanics. It's a very good way to learn them. Reading those doesn't give you technique. You need to work problems and read more conventional texts that have more details if you really want to do quantum mechanics or [be a] general relativist. That's the way I learned. It's a very high level of extraction; you fill in the details later.

You need to work problems and read more conventional texts that have more details if you really want to do quantum mechanics or [be a] general relativist.

A third book which influenced me in a more global way is a book by Hermann Weyl. He's probably less known but he was a great mathematician and physicist. The book was called *The Philosophy of Mathematics and Natural Science* which is an exposition of the basic principles of the foundations of mathematics and natural science from the point of view that Descartes and Leibniz would have appreciated, in other words, trying to understand what the structure of those subjects says about fundamental reality and vice versa, a basic epistemological consideration of how we know and what we know inform science and the fact that this dialogue does go back and forth. One of the great events recently for me is that Princeton university press has just reissued Weyl's book and I got to write the preface [smiles].

So those would be the three names.

9. What would you suggest one do to improve, as my mom calls it, the Global Humor Quotient (GHQ)®?

My wife has written a couple of collections of scientific jokes. My suggestion is that people should read that book [laughs]. Like art, like science, humor shouldn't be isolated. It's part of life. One should always be on the look out for it, enjoy it when you find it, and try to do more.

10. Could you tell us the focus of your current research and or projects?

As I mentioned, it's kind of trying to think about the exotic behavior of matter that is allowed by quantum mechanics that hasn't yet been engineered or recognized. So, specifically, I've been thinking that it was thought for a long time that there were only two particles that were possible, bosons and fermions. I realized that there are other possibilities that you could engineer that can occur not in particles in the vacuum but particles within the two can occur in different ways. That's become a huge subject. It would be useful in quantum computing, the idea of making computers that use quantum mechanical principles and be more powerful. And so I've been fascinated and continue to think okay now that you know that particles like this do exist, how do you use them to do useful things. Since the technology doesn't exist, we have to think creatively of what's possible and how to do it. So that's a continuing enterprise.

Most recently, I've been thinking about something that I call time crystals. Crystals are ordered in space, so if you move a little bit you get the same structure. But if you move a very little bit, you don't get the same structure. It only goes over itself after a finite translation of length. So I've been thinking about things that behave like that not in space but in time. At first I thought that would be easy then I thought it was impossible.

Now I've come to think it's barely possible. It opens up questions like spontaneous emergence of structure and time.

Another thing I've been thinking about, turns out involves some of the same mathematics, is the idea that you can have discontinuous changes in space topology. So topology of space depends on its continuous properties but not its detailed structure. Basically, the idea is that when you have quantum mechanics on a space, because quantum mechanics is based on wave functions and positions and so forth, some peculiar things can happen to space. It can rip apart and come together without the quantum mechanics on the space breaking down. So space time can rip and develop funny things, but quantum mechanics can behave perfectly smoothly. I mentioned before in trying to combine general relativity and quantum mechanics we have this problem: space and time fluctuates. Now I'm starting to think that's no big deal. Space and time can fluctuate and cease to be interpretable as space and time. And yet the evolution of the world based on quantum mechanics happily proceeds. It doesn't need space and time to have conventional properties. That's another thing I've been thinking about. It might sound mystical, but there are equations.

Thank you very much!

Vikram Ramkumar *is a junior studying computer science and astrophysics.*

Kunzang Kazi *is a senior majoring in chemical engineering and minoring in environmental engineering.*

Suggested Readings

IF YOU ENJOYED:

Physics: Then & Now
by Tasneem Hossain

A Cultural History of Physics
by Karoly Simonyi and David Kramer

The History of Physics
by Isaac Asimov

Beyond Einstein: The Quest for the Theory of the Universe
by Michio Kaku

Archimedes to Hawking: Laws of Science and the Great Minds Behind Them
by Clifford Pickover

Career Spotlight: Physics & Law
by Sarah Rizk

Not So Obvious: An Introduction to Patent Law and Strategy
by Jeffrey Schox

Turning Points: Changing Your Career from Science to Patent Law
by Dustin Holloway

Hadron Radiotherapy
by Jeffrey Samuel

Proton Therapy Physics
by Harald Paganetti

Proton and Charged Particle Radiotherapy
by Thomas DeLaney

Hadrons, Nuclei and Applications
by Giovanni Bonsignori et. al.

The Higgs boson
by Tasneem Hossain

Higgs Discovery: The Power of Empty Space
by Lisa Randall

The Higgs Boson: Searching for the God Particle
by Scientific American Editors

Quantum Computing
by Walter Church IV

Quantum Computing Since Democritus
by Scott Aaronson

Natural Computing: DNA, Quantum Bits, and the Future of Smart Machines
by Dennis Shasha and Cathy Lazere

The Bit and the Pendulum: From Quantum Computing to M Theory—The New Physics of Information
by Tom Siegfried

Water or an Anomaly?
by Gabrielle Rejouis

Water on Mars and Life
by Tetsuya Tokano

Frontiers of Power Transmission
by Jennifer Ligo

Superconductivity: A Very Short Introduction
by Stephen J. Blundell

Particle Physics and Biomedicine
by Abhishek Trivedi

Principles of Protein X-Ray Crystallography
by Jan Drenth

An Interview with Frank Wilczek
by Vikram Ramkumar & Kunzang Kazi

The Theory of Relativity and Other Essays
by Albert Einstein

The Principles of Quantum Mechanics
by P. A. M. Dirac

Philosophy of Mathematics and Natural Science
by Hermann Weyl and Frank Wilczek

Fantastic Realities: 49 Mind Journeys and a Trip to Stockholm
by Frank Wilczek and Betsy Devine

Absolute Zero Gravity: Science Jokes, Quotes and Anecdotes
by Betsy Devine and Joel Cohen

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References

Physics: Then & Now
by Tasneem Hossain
Page: 9

[1] Serway, Raymond A., John W. Jewett, and Vahé Peroomian. *Physics for Scientists and Engineers with Modern Physics*. Belmont, CA: Brooks/Cole, 2010. Print.

[2] Mountain Empire High School Class of 1996. "Particle Physics Timeline." The Particle Adventure. Web.

[3] Thompson, Nick. "What Is the Higgs boson and why is it important?" CNN.com, 16 July 2012. Web.

Image credit:
Karsh, Yousef. "Albert Einstein." 1948. The Metropolitan Museum of Art.

Dotzler, Jim. *E8*. Digital image. 2011. Web.

Career Spotlight: Physics & Law
by Sarah Rizk
Page: 12

[1] "General Requirements." The United States Patent and Trademark Office, 23 Jan. 2013. Web.

[2] *Sancho v. U.S. Department of Energy*. District Court of Hawaii. 26 Sept. 2008. Web.

[3] O'Neill, Ian. "Hawaiian Man Files Lawsuit Against the Large Hadron Collider (LHC)." Universe Today, 28 Mar. 2008. Web.

[4] Buchen, Lizzie. "Taking Particle Physics to Court." *Discover Magazine*, 29 Mar. 2008. Web.

[5] Harris, David. "LHC Lawsuit Dismissed by US Court." Symmetry. Fermilab/SLAC, 26 Aug. 2010. Web.

Image credit::
Kneller, Godfrey. *Isaac Newton*. 1689. Digital image. Web.

Thompson, Christina. *Gavel*. Digital image. 11 Dec. 2012. Web.

David & Jessie. *Abraham Lincoln's U.S. Patent*. Digital image. 23 Jun. 2006. Web.

Hadron Radiotherapy
by Jeffrey Samuel
Page: 16

[1] Breneman, John. "Conventional Radiotherapy." PrecisionRadiotherapy.com, Sept. 2003. Web.

[2] Braccini, Saverio. "Medical Applications of Particle Physics." Lecture, Laboratory for High Energy Physics, University of Bern. CERN. 14 July 2008. Web.

[3} Povh, Bogdan, Martin Lavelle, Klaus Rith, Christoph Scholz, and Frank Zetsche. *Particles and Nuclei: An Introduction to the Physical Concepts*. Berlin: Springer, 2004. Print.

[4] Chaudhri, M. Anwar. "Production and Potential Implication of Secondary Neutrons within Patients Undergoing Therapy with Hadrons." American Institute of Physics: Sixteenth International Conference. University of Tuebingen, 2001. Web.

[5] Paganetti, Harald, Alexei V. Trofimov, Chuan Zheng, Drosoula Giantsoudi, and Clemens Grassberger. "Relative Biological Effectiveness of Protons and Heavy Ions." Massachusetts General Hospital Physics Division, 2007. Web.

Image credit:
CERN. *LHC*. Digital image. 2007. Web.

Dagana. *Exotic Matter.* Wikidot.com, 05 Jan. 2013. Web.

Higgs boson
by Tasneem Hossain
Page: 20

[1] "The Standard Model." CERN Accelerating Science. CERN. Web.

[2] Serway, Raymond A., John W. Jewett, and Vahé Peroomian. *Physics for Scientists and Engineers with Modern Physics*. Boston, MA: Brooks/Cole, 2012. Print.

[3] Thompson, Nick. "What Is the Higgs boson and why is it important?" CNN.com, 16 July 2012. Web.

Image credit:
CERN. *Higgs boson.* Digital image. Web.

Fermi Lab. *Standard Model*. Digital image. Web.

Quantum Computing
by Walter L. Church IV
Page: 24

[1] “Moore’s Law.” Moores Law. Web.

[2] Bone, Simon, and Matias Castro. “A Brief History of Quantum Computing.” Department of Computing, Imperial College of London. Web.

[3] Ismael, Jenann. “Quantum Mechanics.” Stanford Encyclopedia of Philosophy, 01 Sept. 2009. Web.

[4] Vazirani, Umesh. “Qubits and Quantum Measurement.” University of California, Berkeley, Web.

[5] Vazirani, Umesh. “Intro, Qubits, Measurements, Entanglement.” University of California, Berkeley. Reading.

[6] Omer, Bernhard. “Shor’s Algorithm for Quantum Factorization.” Vienna University of Technology, Web.

[7] Castagnoli, Giuseppe, and David Finkelstein. “Theory of the Quantum Speed-up.” *Proceedings of the Royal Society A* 457, no. 2012 (08 July 2001): 1799-1806. Web.

[8] Bacciagaluppi, Guido. “The Role of Decoherence in Quantum Mechanics.” Stanford Encyclopedia of Philosophy, 16 Apr. 2012. Web.

[9] Preskill, John. “Reliable Quantum Computers.” *Proceedings of the Royal Society A* 454, no.1969 (08 Jan. 1998): 385-410. Web.

[10] Preskill, John. “Quantum Computing: Pro and Con.” *Proceedings of the Royal Society A* 454, no.1969 (08 Jan. 1998): 469-486. Web.

[11] “InAs Quantum Dots Offer a New Route to Large-scale Quantum Computing.” CS Compound Semiconductor, 25 Oct. 2012. Web.

Image credit:
Novagen, Adam. *Quantum Computer*. Digital image. DeviantART. Web.

Water or an Anomaly?
by Gabrielle Rejouis
Page: 27

[1] Franzese, Giancarlo, and J. Miguel Rubí, eds. *Aspects of Physical Biology: Biological Water, Protein Solutions, Transport and Replication*. Berlin: Springer, 2008. Print.

[2] Ravilious, Kate. “How long can someone survive without water?” The Guardian, 02 Dec. 2005. Web.

[3] Matthews, Robert. “Water: the quantum elixir.” *NewScientist* 2546 (08 Apr. 2006): 32-37. Web

[4] “Chemistry Tutorial: The Chemistry of Water.” The Biology Project. The University of Arizona, 28 Jan. 2003. Web.

[5] McCulloch, David L., Ph.D. “Chapter 3: Water and the Fitness of the Environment.” Collin County Community College, 15 July 2003. Web.

[6] Nave, Carl R. “Specific Heat.” HyperPhysics.com. Georgia State University, 07 June 2004. Web.

[7] Waltham, Chris. “An Early History of Heavy Water.” (21 Oct. 2011): arXiv:physics/0206076. Web.

[8] Castelvecchi, Davide. “Quantum Effects Make H_2O Weird.” *Science News* 174.4 (16 Aug. 2008). Print.

[9] Phillips, Rob, Jane Kondev, and Julie Theriot. *Physical Biology of the Cell*. New York: Garland Science, 2009. Print.

[10] Cartlidge, Edwin. “Physicists discover new quantum state of water.” PhysicsWorld.com. Institute of Physics, 04 Feb. 2011. Web.

[11] “Stony Brook University Researchers Discover Significant Water Anomaly.” Newswise.com. Stony Brook University, 08 May 2012. Web.

[12] “Water Questions & Answers: Why Is Water the “Universal Solvent”?” U.S. Geological Survey. U.S. Department of the Interior, 09 Mar. 2012. Web.

[13] LaJeunesse, Sara. “Splitting Water 2.0: Cluster geometry is key to splitting water at room temperature.” Penn State News. Penn State University, 01 June 2009. Web.

[14] “Rebirth: Cluster of Excellence.” Rebirth.com. Rebirth, Hannover, 2013. Web.

Image credit:
trancedman. *BlueWater*. Digital image. DeviantART. Web.

Frontiers of Power Transmission
by Jennifer Ligo
Page: 30

[1] Rabinowitz, Mario. “Advanced Power Transmission of the Future.” (19 Apr. 2003) arXiv:physics/0304070. Web.

[2] “Frequently Asked Question.” U.S. Energy Information Administration, 09 July 2012. Web.

[3] Hokin, Samuel. “Transmission Lines.” The Physics of Everyday Stuff, 2013. Web.

[4] “High Power HTS Transmission Cable.” Superconductor Technologies Inc., 2013. Web.

[5] Lindley, David. “Focus: Landmarks: Superconductivity Explained.” Physics: spotlighting exceptional research. American Physical Society, 11 Sept. 2006. Web.

[6] Ehrlich, David. “Superconductor Cable Gets Energized on Long Island.” Global Energy Network Institute, 30 Apr. 2008. Web.

[7] “Superconductor Applications.” Superconductor Week, 2011. Web.

Image credit:
Tange, Lennart. *Pylon*. Digital image. Flickr. 30 Dec. 2012. Web.

LIPA power grid. Digital image. American Superconductor, Apr. 2008. Web.

Particle Physics & Biomedicine
by Abhishek Trivedi
Page: 33

[1] Atteberry, Jonathan. "What Exactly Is the Higgs boson?" HowStuffWorks, Inc. Web.

[2] "What Is X-Ray Crystallography?" InnovateUs Inc., 2005. Web.

[3] Nelson, Stephen A. "X-Ray Crystallography." X-Ray Crystallography. Tulane University, 19 Oct. 2011. Web.

[4] Arkin, Michelle R., and James A. Wells. "Small-molecule inhibitors of protein–protein interactions: progressing towards the dream." *Nature Reviews Drug Discovery* 3.4 (Apr. 2004): 301-317. Scopus. Web.

[5] Foster, Catherine. "Research at Argonne helps Abbott Labs develop anti-HIV drug."

Image credit:
Heoh. *Molecule Structure, Mesh, the Microscope.* Digital image. Goodfon.com. Web.

An Interview with Frank Wilczek
by Vikram Ramkumar & Kunzang Kazi
Page: 36

[1] Wilczek, Frank. "The Frank Wilczek Web Site." Frank Wilczek. Web.

Photo credit:
Wilczek, Amity. *Frank Wilczek at 2004 Nobel Prize*. 2004. Digital image. Web.

CERN. *Image of CERN*. Digtal image. Web.

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Physics Mathematics Chalk. Digital image. OnlyHDWallpapers. Web.

Opening Image:
Page: 3
Ali, Reza. *Processing Particle Study.* Digital image. 14 May 2009. Web.

Image of NJIT Students:
Page: 4
Kazi, Kunzang. "*Honors students*." 2013.

Flip book Art:
Kozhynova, Valeriya. 2013.

Taylor, Lucas. *CMS–Higgs event*. Digital image. 1997. Web.

The Miraculous Formation of Carbon. Digital image. Design and Universe. Web.

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STAR. *Gold Beam Collision Recorded at STAR,* 31 Jan. 2012. Digital image. Web.

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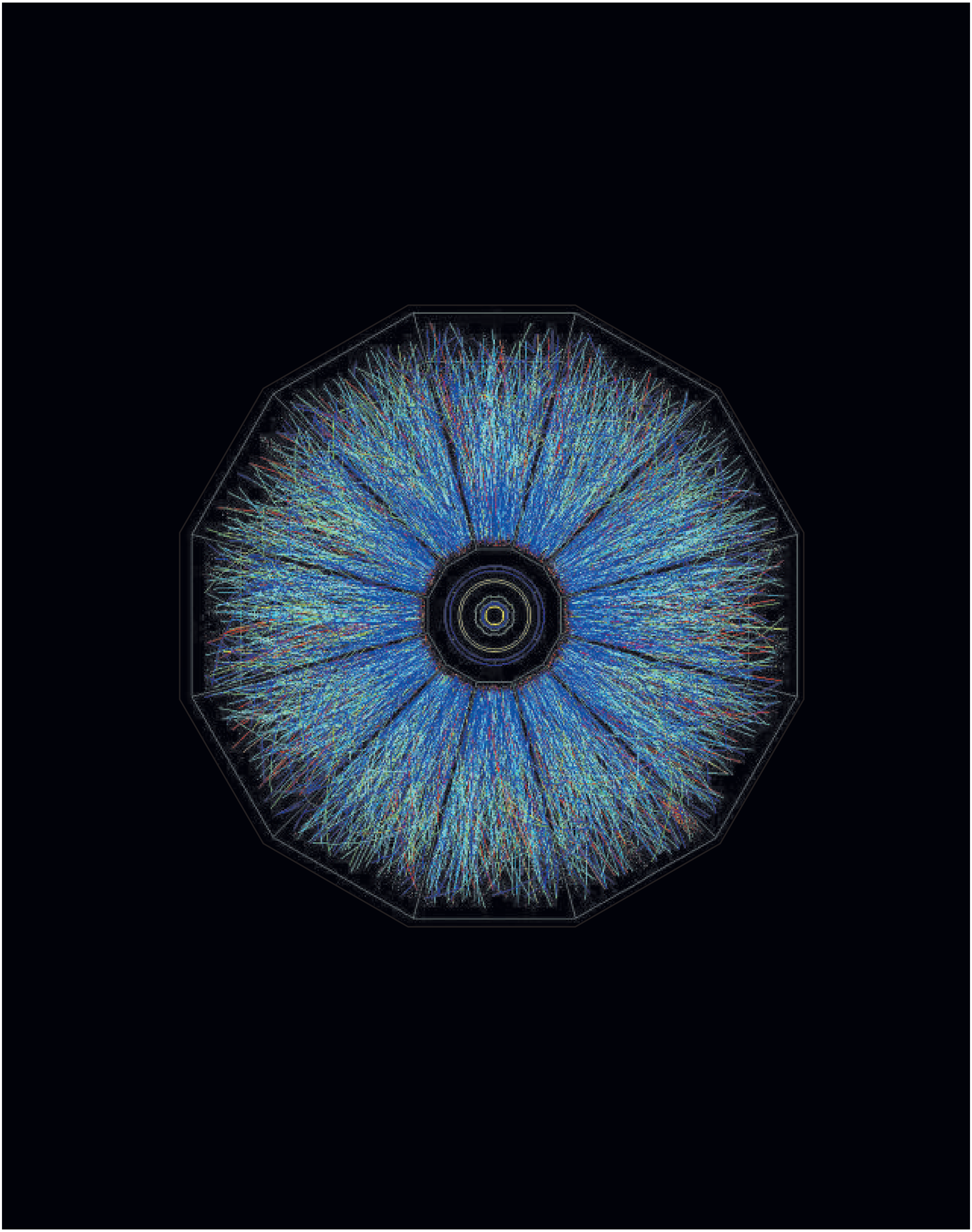

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