THE WALK OF LIFE

VOL. 03

EDITED BY AMIR A. ALIABADI

The Walk of Life

Biographical Essays in Science and Engineering

Volume 3

Edited by Amir A. Aliabadi

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2018

ISBN: 978-1-7751916-1-2

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It should be distinctly understood that this [quantum mechanics] cannot be a deduction in the mathematical sense of the word, since the equations to be obtained form themselves the postulates of the theory. Although they are made highly plausible by the following considerations, their ultimate justification lies in the agreement of their predictions with experiment.

—Werner Heisenberg

Dedication

Jahangir Ansari

Preface

The essays in this volume result from the Fall 2018 offering of the course *Control of Atmospheric Particulates* (ENGG*4810) in the Environmental Engineering Program, University of Guelph, Canada. In this volume, students have written about Charles-Augustin de Coulomb, Werner Heisenberg, Srinivasa Iyengar Ramanujan, Muhammad ibn Musa Al-Khwarizmi, Leonhard Euler, Adolf Eugen Fick, James Clerk Maxwell, Robert Hutchings Goddard, Nikolai Albertovich Fuchs, and Josiah Willard Gibbs. Students have accessed valuable literature to write about these figures. I was pleased with their selections while compiling the essays, and I hope the readers will feel the same too.

Amir A. Aliabadi

Acknowledgements

Particular thanks go to my graduate student and teaching assistant for the course, Hossam Elmaghraby Abdelaal, who examined and evaluated the essays. I am also indebted to my brother, Reza Aliabadi, a life-long mentor and inspirer for my ideas and directions in life, who also designed and executed the cover page for this volume. At last, I am thankful to each individual student author, without whom this project would not have been possible.

Amir A. Aliabadi

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By Zimeng Wan, Mamoon Syed, Yunxi Jin, Jamie Stone, and Jacob Murphy

When we think of famous physicists many names typically come to mind: Albert Einstein, Isaac Newton, Niels Bohr, Stephen Hawking, and the list goes on. All of these scientists had incredibly successful careers generating groundbreaking research that, in many cases, fundamentally changed how their field of study was viewed. Because of their successes, many of these scientists became household names forever associated with academic proficiency and the field of physics itself. Unfortunately however, one such scientist, Charles-Augustin de Coulomb, is much less of a household name. Despite this fact, the contributions that Coulomb made to the study of physics should not be undervalued. Coulomb is most well known in modern day for his work in the field of electrostatics but made other contributions to different areas of mechanics throughout his career.

1.1 Early Years Against the Norm

Charles-Augustin de Coulomb was born in Angoulême, France, on June 14, 1736 as the third child to parents Henri Coulomb and Catherine Bajet (Dowson, 1978). Both of Henri and Catherine were of a high societal standing, coming from wealthy families, and Henri was working as a legal professional with some political connections. Soon after Charles-Augustin de Coulomb was born, his family moved to Paris, France, due to his father's work. Catherine had high aspirations for her son, and early on in his young-adult life she enrolled him in the Collège Mazarin, one of the most highly regarded secondary schools in Paris at the time. Despite the wealth and social standing of the Coulomb family, they were not considered as aristocrats and were therefore not privy to some of the social and economical advantages provided at this time. This resulted in Charles-Augustin being one of the school's unofficial students, with the institution not allowing him full admission. Even though he was not considered a full student at the time, the Collège Mazarin educated Coulomb in the fields of language (Falconer, 2004), literature, and philosophy. At some point later in his education, Coulomb heard of an astronomer, Charles Pierre Le Monnier, who was providing lectures at a different institution known as the Collège Royal de France. Curious, Coulomb attended many of Monnier's lectures which furthered his interest in the science as well as providing him with a strong background in Newtonian mechanics. This interest in the sciences also resulted in Coulomb taking classes in mathematics, astronomy, chemistry, and botany back at Collège Mazarin. This decision to pursue a more scientific education was disliked by Coulomb's mother, resulting in the two becoming somewhat estranged (Falconer, 2004).

Around the same time, Coulomb's father had moved south to Montpellier, France, because of some financial difficulties he had in business dealings in Paris. Due to the disagreements with his mother, Coulomb joined up with his father in Montpellier in the year 1757 (Oliveira, 2016). While in Montpellier Coulomb joined up with the Society of Sciences of Montpellier. This allowed him to further his interests in the fields of both mathematics and astronomy due to the many scientific papers at the disposal of this Society. Later in the same year, Coulomb decided that to continue his education he was going to have to receive a formal education at a proper institution. This decision lead him to move back to Paris in late 1758 in order to receive tutoring to prepare him for the entrance examinations into the École du Génie at Mézières.

By 1760 Coulomb was enrolled in the engineering program of Mézières (Falconer, 2004), a military funded program at the school. During his time in school, Coulomb continued his scientific study, gaining both a fundamental theoretical understanding of mechanics as well as experiencing practical engineering skills. This practical education included many building projects in the local community. Coulomb successfully graduated as a trained engineer as well as earning the rank of lieutenant in the Corps de Génie in the process in November 1761 (Oliveira, 2016). The formative years of Charles-Augustin de Coulomb are very telling for his determination and resilience of character as well as illustrating his love and connection to the academic field, specifically to the pursuit of scientific knowledge. His willingness to go against his family's wishes and pursue a scientific education and join a community dedicated to learning showed his own dedication to his scientific passion that would not be easily quelled. Additionally, his persistence in pursuing enrolment into an education despite not hailing from a class that typically could participate in such an institution further shows his determination to be part of something greater. The work performed and scientific discoveries achieved by Coulomb are owed to his efforts at an early age.

1.2 The Military Engineer

Charles-Augustin de Coulomb began his professional career in the field of military engineering. Over his years served in the French military, Coulomb accumulated practical experience in fortification, structural building design, and soil mechanics, just to name a few. His first posting was to Brest, France, in the immediate aftermath of his graduation in 1761 but was relatively uneventful. This would all change for Coulomb in February 1764 (Falconer, 2004) when a fellow military engineer fell ill at the posting of Martinique in the West-Indies. As a result, Coulomb was transferred to Martinique. Martinique was under the control of France at the time, however it was often the target of attacks from both the English and the Dutch armies as recently as 1762. The signing of the Treaty of Paris in 1763 ensured the control of Martinique to France, but the French ruler at the time, Louis XV *le Bien-Aimé* (or *the Beloved*), insisted that the island colony be fortified to defend against future attacks should the treaty be broken. The task of completing this fortification was handed to Coulomb upon his appointment to Martinique in 1764 (Dowson, 1978). The time that Coulomb spent constructing Fort Bourbon allowed him to apply his engineering education in an impactful manner.

His work on Fort Bourbon also formed the basis of his subsequent research in the field of applied mechanics. Coulomb wrote memories at the time, documenting his work on Fort

Bourbon, which would later go on to form the basis of the scientific field of soil mechanics. From these memories, investigative theories outlining mechanical friction, cohesion, and the flexure of structural beams as well as the shear force capabilities of different brittle materials have all been derived. This was not however used at the time as few other engineers would use Coulomb's methods until later in the future. This was partly do to the fact that much of Coulomb's work was comprised of mechanisms for ensuring the stability and longevity of a project and did not define any laws, rules, or tables for use in this field. The oversight of the project of fortifying the settlement in Martinique took Coulomb until the June of 1772 (Dowson, 1978). The time that Coulomb spent in Martinique was not all positive unfortunately. He was plagued by illness and other health concerns during his time there, and even after his return to France, he was affected by these health concerns for the rest of his life. On the lighter side, the knowledge gained from Coulomb's practical experience in Martinique would go on to shape the rest of his career.

1.3 Mathematics, The Language for Engineering

Upon returning to continental France, Coulomb moved to Bouchain (Oliveira, 2016), a community in the north of the country. It was there where he began some of his most defining research into the field of applied mechanics. In 1773 he presented his first findings on friction and cohesion to the Académie des Sciences based on the writings he had done in his Martinique memoirs. His application of mathematics and calculus being used to solve his engineering problems with Fort Bourbon were significant at the time. Prior to Coulomb, the concept of applying sophisticated mathematical principles to rudimentary manual labor tasks was not common. This publication led to Coulomb becoming a correspondent for the Académie des Sciences, allowing him to provide news on his research to the academy directly. His first recognized honour from the Académie des Sciences came in 1777 (Falconer, 2004) and was for his work on an explanation for the magnetic nature of the earth as well as his work with compasses. In 1779 Coulomb traveled to Rochefort in order to work alongside fellow engineer Marquis de Montalembert.

Like Coulomb, Montalembert had cultivated a reputation for his engineering prowess while working with the military to fortify settlements and colonies. In Rochefort, Coulomb performed some of the most critical research of his career. He used the laboratories and the shipyards in Rochefort to continue his research in applied mechanics (Falconer, 2004). The most noteworthy research he performed at the time was in the study of friction, which led him to write his book *Théorie des Machines Simple* which earned him even greater praise from Académie des Sciences. He won an academy prize for his work on friction and in the process, essentially made friction a new field of scientific study. As a result of his work, Coulomb was elected to be a member of the Académie des Sciences in 1781 (Oliveira, 2016) and moved back to Paris in the process. With his new membership status and the prize money he earned for his work, Coulomb no longer had to work as a structural engineer, however he did remain as a consultant on choice for few projects. This allowed Coulomb to focus the majority of his time and energy on his own research. It was during this time that Coulomb began work on the field of electrostatics, the field in which he is most well-known in modern day.

1.4 The Beginning of Electrostatics

He submitted seven papers to the Académie des Sciences between the years of 1785 and 1791, all on the topic of electrostatics (Falconer, 2004). These papers contained research that would fundamentally change how electricity and magnetism were viewed in the world of science. The papers outlined the fact that bodies of the same polar electrical charge would repulse one another and that bodies of opposite polar electrical charge would be attracted to one another. This was the basis of the Theory of Attraction and Repulsion that is still used to this day. In these papers Coulomb also demonstrated how the Inverse Square Law can be directly applied to electrostatics (Oliveira, 2016). He showed that the electrical field strength of a body is a function of the charge from the point source, the area of the spherical body and the radial distance from the source. The electrical force illustrated by the Inverse Square Law became known as Coulomb's Law, which again, is still used in electrical engineering and circuitry in modern times. The final major finding illustrated in these scientific papers was his work into conductors and dielectric insulators. Coulomb stated that there is no substance that exists that acts as a perfect electrical insulator. He stated that every dielectric material has a limit to the amount of electricity that it can insulate from and when that limit is reached, the dielectric will begin to conduct electricity. This principle is still used today, with electronics manufacturers having to take special care to ensure that their devices are made of a substance that can handle a specific electrical charge running through the device.

1.5 Dedication to Community and Final Years

Charles-Augustin de Coulomb was not just an important research consultant to the Académie des Sciences, but he was actively involved in his community. He was involved with hundreds of committees during his twenty-five-year association with the Académie des Sciences, providing feedback to and having influence on many other French scientists and physicists of the time. Coulomb also applied himself to the betterment of public welfare. He worked alongside the governments of the time to provide his inputs on both the medical and education institutions. Coulomb also aided in maintaining and developing the water systems in Paris, which included work on the Royal Fountains. Coulomb also had two sons with his eventual wife Louise Françoise LeProust Desormeaux, one born in 1790 and the other in 1797 (Oliveira, 2016). In 1791 Coulomb retired from the Corps du Génie and later in 1793 left the committee of the Académie des Sciences. After his retirement and resignations, Coulomb and his family moved to a house he owned near Blois, France. In his retirement, Coulomb continued his scientific research; however he did not make any major scientific advancements in this time. In 1796 Coulomb became afflicted with a fever that was related back to the illness he sustained while working at Martinique. Coulomb passed away in Paris on August 23, 1806 (Oliveira, 2016).

1.6 Multifaceted Contributions

Charles-Augustin de Coulomb was an immensely important scientist in the field of mechanics. The work done by Coulomb through his time in the French military as well as during his association with the Académie des Sciences fundamentally changed the landscape of science. He essentially created the fields of research in both soil mechanics as well as mechanical friction, fields not formerly recognized prior to his work. Additionally, Coulomb's theories and work in electrostatics are being felt today with much of his research still being used by modern scientists. The work accomplished throughout the career of Charles-Augustin de Coulomb cannot be understated.

2 Werner Heisenberg (1901-1976)

A Life of Uncertainty

By Greg Johnstone, Thomas Jackson, Michael MacGregor, and Ketan Suresh

Apple Inc.'s 1997 *Think Different* campaign began with a commercial: "[Crazy people] push the human race forward, and while some may see them as the crazy ones, we see genius, because the people who are crazy enough to think that they can change the world, are the ones who do." Werner Karl Heisenberg was an exemplar of this mindset to his very end. Within this paper, the genius of Heisenberg will be showcased along with his lesser known personal life: from his early years in Munich, Germany, to his immense contributions to many fields, such as quantum mechanics, particle physics, and ferromagnetism. With certainty or uncertainty, we delve into the life of Werner Karl Heisenberg.

2.1 Early Life

Werner Karl Heisenberg was one of the greatest theoretical physicists of the modern era. Before that he was a humble boy who was born on the fifth of December 1901 to Kaspar Ernst August

Heisenberg and Annie (Wecklein) Heisenberg. Werner's father was a classical languages teacher at a secondary school, and his mother Annie stayed at home with the children. Ultimately, his father's love for academic learning inspired Heisenberg to pursue a career in science.

World War I (WWI) and its aftermath had a profound effect on the young Heisenberg, as he witnessed the impact of the War's embargo and the upheaval of the monarchy on German Society (Cassidy, 1992). This resulted in him being very active in the German youth movements. He was a member and scout leader of the Bund Deutscher Neupfadfinder, an organization similar to the Boy Scouts of America.

Werner was an avid hiker, and a dedicated hard worker who worked summers on a farm to help pay for his university tuition. Heisenberg from a young age had many talents. Throughout his life, music was very important to him; by the age of thirteen he was able to play compositions meant for masters (Chatterjee, 2004). Extremely intelligent he taught himself calculus and attempted to have his own papers published as a teenager.

He later studied mathematics and physics while attending university at Ludwig-Maximilians-Universitat München and the Georg-August-Universitat Göttingen from 1920 to 1923. While attending university, he studied under Arnold Sommerfeld and Wilhelm Wien in Munich, and he studied physics with James Planck and Max Born at Göttingen.

In 1922, Arnold Sommerfeld took Heisenberg to the Bohr Festival where Niels Bohr was speaking because Sommerfeld knew of Heisenberg's exorbitant interest in Bohr's theories on atomic physics. Bohr gave numerous lectures on quantum physics at the festival, which is where Heisenberg and Bohr met for the first time. Bohr had an immeasurable effect on Werner throughout his life.

In 1923, Heisenberg received his doctorate degree. His topic of choice, turbulence, was suggested by Sommerfeld. The thesis focused on the nature of laminar and turbulent flows and each state's stability. The key investigative tool was the Orr-Sommerfeld fourth order linear differential equation designed to work with small disturbances from laminar flow.

2.2 Theoretical Physics

Heisenberg was referred to as a *magician-physicist* from modern-day physicist Steven Weinberg (Satija, 2016). This title is in reference to his research and his style of developing his theories. Weinberg believes that Heisenberg's approach to theoretical physics "does not seem to be reasoning at all, but [Heisenberg] jumps all over intermediate steps to a new insight about nature" (Satija, 2016). Heisenberg knew of and was privy to his unorthodox methods as he wrote: "It should be distinctly understood that this [quantum mechanics] cannot be a deduction in the mathematical sense of the word, since the equations to be obtained form themselves the postulates of the theory. Although they are made highly plausible by the following considerations, their ultimate justification lies in the agreement of their predictions with experiment" (Plotnitsky, 2016). Heisenberg's methodology proved to be credible as they led to the fundamental basis of quantum mechanics.

Upon his graduation from Munich, Heisenberg began lecturing at the University of Göttingen. The position eventually led to the opportunity to conduct theoretical physics research with Neils Bohr at the University of Copenhagen. With the assistance of Neils Bohr, Heisenberg extended the use of the Bohr atom model into a new form of mechanics. The system interprets the physical properties of atomic particles and expresses them in a matrix. This research led to the first complete and correct definition of quantum mechanics, known as matrix mechanics (Cassidy, 1992). Heisenberg's famous 1927 uncertainty principle was another breakthrough developed during his time working with the University of Copenhagen, which disrupted Newton's clockwork universe.

Heisenberg published his uncertainty principle, that stated particles do not follow straight forward Newtonian laws, where the end conditions can be calculated given the starting conditions. The motivation for Heisenberg's new theory was said to be derived from a conversation with Albert Einstein in 1926. During this conversation Einstein questioned Heisenberg's philosophy on Nature. The conversation led to Einstein's famous quotation "Only the theory decides what one can observe" (Cassidy, 1992). Heisenberg saw this as an attack on his fundamental basis in which he developed his theories. Heisenberg later expanded on Einstein's quote by explaining "While the theory determines what can be observed, the uncertainty principle showed him [Einstein] that a theory also determines what cannot be observed" (Cassidy, 1992).

The uncertainty principle proclaims that a position x and a momentum p cannot be measured with absolute certainty at the same time. It is further explained by stating that obtaining a more accurate measurement of position will decrease the accuracy of momentum's measurement and vice-versa. A macro-scale example of this phenomenon would be measuring the change in the path of a thrown basketball after it impacted a thrown tennis ball. The change can tell us where the tennis ball was at impact, but not much of its momentum. The uncertainty principle is used for the explanation of numerous phenomena in quantum physics. Alpha decay, for example, is a type of nuclear radiation that is caused by two neutrons and two protons escaping the nucleus of another atom. The particles' escape is justified using the uncertainty principle by acknowledging that the position of the particle is very precise and therefore the velocity is very unknown, possibly large enough to escape.

2.3 Ferromagnetism

Heisenberg's efforts with magnetism proved the applicability of his theories in quantum mechanics. Heisenberg used his knowledge in quantum mechanics to simplify Weiss' theory on molecular fields (Chikazumi, 2009; Mnyukh, 2012).

The phenomenon of magnetism has been known since 600 BCE by the Ancient Greeks, but it was not till the nineteenth century that studies were undertaken (Chatterjee, 2004). Including and up to the 1920s physicists failed to understand magnetic properties an atomic level of understanding (Chatterjee, 2004). Heisenberg's theory on quantum mechanics helped fill this void.

Before Heisenberg's discovery, the phenomenon of ferromagnetism escaped explanation. Ferromagnetism, the strongest magnetic phenomenon, occurs when the poles of a magnet are laid in a uniform direction. The Curie-Wiess Model could fully explain many magnetic phenomena like paramagnetism, a multidirectional magnetism; but ferromagnetism escaped its definition (Chikazumi, 2009). The Curie-Wiess Model attempts to explain ferromagnetism by asking to pretend there is a second field to the external field. The assumption is that the imaginary field, a Wiess Field, influences the direction of the magnet into ferromagnetic orientations (Chikazumi, 2009). Heisenberg was the first to connect the phenomena of electron bonding and ferromagnetism, which proved to be the foundation of the Weiss molecular field. It still had to justify ferromagnetism in certain metals, but it gave meaning to the Wiess' imaginary field. It was also Heisenberg's quantum dynamics that allowed for the understanding of the atomic spectra in relation to ferromagnetism. Heisenberg's work in ferromagnetism also expanded into the world of Hamiltonian Mechanics, which attempts to describe classical mechanics using phase states and time. Heisenberg's Hamiltonian theory is a widely applicable theory, allowing for the investigation into spin dynamics and thermodynamics . Heisenberg's theories in this area are used in modern magnetism to investigate the magnetic properties of metals.

2.4 The Uranium Club

The *Uranprojekt* or *Uranverein* was a Nazi program to investigate the potential to produce nuclear weapons in World War II (WWII) (Bernstein, 2001). Prior to Heisenberg conducting research for the *Uranverein*, Uranium Club, his theories were attacked by the Nazi Waffen-SS being labelled as "Jew Physics" (Bernstein, 2001). There was an article in the official journal of the SS that stated Heisenberg and all theories of quantum physics were perceived as non-German but Jewish thinking. Heisenberg used his family connection to receive an exoneration on behalf of Heinrich Himmler, the head of the SS at the time.

Heisenberg joined the Uranium Club shortly after the outbreak of World War II, where he was tasked with nuclear fission research. Within two months of his work Heisenberg established himself as the leading authority on nuclear fission. Heisenberg published his finding in 1939, stating that the controlled fission reactor would produce a bomb "which surpasses the explosive power of the strongest explosive materials by several orders of magnitude" (Bernstein, 2001). Heisenberg's technical report would be the fundamental approach for the research throughout the remainder of the war.

During the war Germany had nine task-oriented research groups. Heisenberg was head of one of two research groups focused on the construction of a reactor, which was located in Leipzig, as well as an advisor on the Berlin research group. Come 1942 Heisenberg took charge of both research facilities and spilt his time equally. This allowed Heisenberg to have a large impact on both of Germany's reactor projects.

Heisenberg's participation in the Uranium club is well documented, being the most prestigious out of the six leading scientists (Bernstein, 2001). Heisenberg's exact influences in the group, however, are unclear, as there are arguments presented that claim Heisenberg had in-depth knowledge on how to build a bomb that he deliberately withheld from everyone (Bernstein, 2001). After his death, his wife supported the claims of insubordination. She often stated that during a meeting with Bohr, Heisenberg tried to persuade him that some sort of international agreement should be reached before nuclear weapons are made and used (Bethe, 2000). Heisenberg was also accused of trying to pass German intelligence onto the Allies, a claim that was backed up by drawings that were given to Bohr during their last meeting that were transmitted to Los Alamos, the birth place of the first atomic bomb (Bernstein, 2001).

2.5 Later Work and Accomplishments

After World War II, Heisenberg worked to change the direction of his scientific research. In 1953, he became the president of the Alexander von Humboldt Foundation. He was tasked with gathering of international scientists and allowing them to work in Germany. From the early 1950s onwards, he focused his research on a "unified theory of fundamental basic particles" emphasizing the importance of symmetry principles. The purpose of this research was to characterize physics of elementary particles. From 1957, he also became involved in plasma physics and thermonuclear processes. He also worked with the International Institute of Atomic Physics at Geneva. For several years, he served as the chairman of the Scientific Policy Committee of this Institute and significantly steered this Committee.

Later in his life, he published several books discussing the influence of atomic and nuclear physics on societies and cultures. Aside from several medals and prizes, Heisenberg received multiple honorary doctorates from the University of Bruxelles, the Technological University of Karlsruhe, and the University of Budapest. He also received the Order of Merit of Bavaria and the Grand Cross for federal services with star. Heisenberg retired in 1970 and passed away on February 1, 1976 due to illness.

3 Srinivasa Iyengar Ramanujan (1887-1920)

Beyond Proof

By Taylr Cawte, Rebecca Beutel, Jocob Van Wassenaer, Ryan Fox, and Nikolaos Veriotes

Srinivasa Ramanujan contributed thousands of theorems to the field of mathematics that are described as nothing less than extraordinary. Almost 100 years after his death, mathematicians like Ken Ono are devoting an entire career to extending and proving Ramanujan's results. While other mathematicians are publishing their research only learn that Ramanujan had already made these discoveries. Ramanujan's theorems are used today by physicists to understand black holes while, during Ramanujan's lifetime, these were unknown (Ono and Aczel, 2016). Even more astonishing is how Ramanujan overcame the difficulties throughout his life having survived disease, famine, extreme poverty, and failing to obtain a degree from school.

3.1 Birth

Srinivasa Ramanujan was born on December 22, 1887 in Erode, Tamil Nadu, to a poor religious Brahmin family. Initially, his mother, Komalathammal, could not conceive during the first few years of her marriage and she believed through devoted prayers to the family deity, goddess Namagiri by her father, she was able to conceive and give birth to a son, Ramanujan. His mother was a housewife, extremely spiritual often having prayer meetings at her home, she would earn five to ten rupees per month singing at the local temple that would help supplement her husband's very modest salary of twenty rupees per month (Kanigel, 1992).

His father, K. Srinivasa Iyengar, worked as an accountant to a cloth merchant in Kumbakonam. He was an absent father, rarely home and paid little attention to Ramanujan when he was at home and did not help his wife raising their son. Ramanujan was fortunate to have been raised by his mother who was a strong-willed and authoritarian woman who affectionately call her son Chinnaswami or "little lord". Like his mother, Ramanujan had the same passionate temperament and grew to resemble his mother and all her bulky body. Ramanujan had a strong bond with his mother; he only left India after his mother gave her permission to do so (Ramanujan, 1927).

3.2 Disease

India was a British colony during Ramanujan's lifetime; famine and disease were common during this period. All Ramanujan's siblings who were born shortly after him died in their infancy, leaving him to grow up as the only child and the focus of the family. He did not have any siblings until he was ten when his mother gave birth to his brother, Lakshmi Narasimhan, in 1898, and he later gained another brother when he was seventeen after his mother gave birth to Tirunarayanan (Ono and Aczel, 2016).

Srinivasa Ramanujan survived his childhood against unimaginable odds that killed thousands upon thousands of people in India. At two years old he survived the smallpox pandemic, a highly contagious disease having a mortality rate of 80% that killed hundreds of thousands around the world. At seven, the stress of his grandfather's death from leprosy caused him to break out in boils. At ten he survived the cholera epidemic that killed fifteen thousand people, then at twenty-three Ramanujan developed hydrocele, an abnormal swelling of the scrotal sac that was likely caused by a mosquito-borne parasite called filariasis that was endemic in South India. He later needed surgery to remove the large hydrocele; his family had no money to pay for the surgery, and his mother asked friends for help, but no one came forward. Finally, in January 1910, Dr. Kuppuswami volunteered to do the surgery for free (Kanigel, 1992).

3.3 Child Genius

As a child he often kept quiet and to himself and like Albert Einstein, born eight years before Ramanujan, began to talk unusually late (Ono and Aczel, 2016). At age five Ramanujan attended the local Kangayan Primary School in Kumbakonam; two years later at seven he was admitted to the Town Hall high school where in 1897 he passed his examinations achieving the top position in the district; this achievement reduced his tuition by 50%. At the age of ten he would tutor his fellow classmates from his window because his parents would not allow him to go outside. It wasn't until his second year in school when his curiosity and obsession were first noticed. In his fourth year he borrowed *Loney's Trigonometry* from his neighbour, a senior student at the school. His neighbour was in amazement that Ramanujan read the book and could solve every problem in the book without any aid. Afterwards, his neighbour would come to Ramanujan to help him solve the more difficult problems of his homework (Thakur, 2004). Later in school Ramanujan independently discovered a formula he thought was original by him only to learn a mathematician, Leonhard Euler, discovered it 150 years earlier. Embarrassed, he hid his paper in the ceiling of his home (Kanigel, 1992).

At sixteen, in his sixth year of school he obtained a copy of *Carr's Synopsis of Pure Mathematics* that his friend borrowed from the local government college. This book was the catalyst that sparked his genius in mathematics. Each equation in the book was a research for Ramanujan, without help, he devised a method to construct magic squares. He then focused his attention to geometry where he was able to calculate the circumference of the earth at the equator within a few feet. He found geometry limiting and changed his attention to algebra; he would often say the goddess of Namagiri inspired him with equations in dreams and upon his awakening he would write notes of his dreams to work on during the day (Thakur, 2004).

3.4 Disappointments at School

In December 1903 Ramanujan passed the Matriculation Examination of the University of Madras and in the new year joined the junior first in arts class of the government college of Kumbakonam winning the Subrahmanyam Scholarship that was awarded to students who were proficient in English and mathematics. Ramanujan's obsession with mathematics continued to grow and engulfing him to the point where he was completely oblivious of what was going on around him and neglecting other subjects resulting in failing to advance in school and consequentially losing his scholarship.

Ramanujan ran away briefly because of his failure but then returned to school again only to fail getting his term certificate in 1905 due to lack of attendance. In 1906 he went to Pachaiyappa's College in Madras and had to withdraw after becoming ill. In December 1907, he wrote the F. A. Examination as a private student and failed again. Having no degree Ramanujan couldn't get stable employment, but he kept on working on mathematics writing in a notebook he always carried with him (Kanigel, 1992).

When he was twenty-two years old, he wanted to get married and settle down. His mother had already found him a bride a year earlier and arranged the wedding without consulting her husband. She was Janaki (Janakiammal) (March 23, 1899 - April 13, 1994), who was ten years old when they married on July 14, 1909. After the wedding Janaki went back to live with her family until she reached puberty, when she returned in 1912 to live with Ramanujan and his mother (Thakur, 2004).

3.5 Supportive Friends

Unfortunately, being from a poor family and not having a degree made it extremely difficult to secure employment. He went to see Mr. V. Ramaswami Iyer, the founder of the Indian Mathematical Society, employed as the deputy collector asking him for a clerical position in the municipal office. Ramanujan showed him his notebooks that Ramaswami thought was incredible and instead of offering him a position he gave him a letter of introduction to Mr. P. V. Seshu Aiyar, the principal of the Government College.

Seshu Airyar already knew Ramanujan; he was his math lecturer while Ramanujan was in school. Seshu Airyar gave Ramanujan a few months of work; after the work ended Ramanujan earned money by private tutoring. Seshu Airyar later sent Ramanujan a letter of recommendation to Diwan Bahadur R. Ramachandra Rao who had already met Ramanujan, thinking it would be cruel to Ramanujan and a waste of his great intellect having to work as a clerk. Rao sent Ramanujan back to Madras offering to pay his expenses.

Returning to Madras Ramanujan made other unsuccessful attempts to secure a scholarship, during which time he continued writing in his notebook. Seshu Aiyar helped Ramanujan publish in the "Journal of the Indian Mathematical Society", on February 1911, asking readers to evaluate x in the infinite nested radicals

$$x = \sqrt{1 + 2\sqrt{1 + 3\sqrt{1 + ...}}} \tag{3.1}$$

In December 1911 he published *Some Properties of Bernoulli Numbers* and in 1912 he contributed two more publications. Six months passed since he asked readers to evaluate the infinite nested radicals, and, with no one coming forward, Ramanujan decided to provide the solution to his infinite nested radicals (Answer $x = 3$).

Ramachandra introduced Ramanujan to Mr. Griffith of the Madras Engineering College to take an interest in him and Griffith contacted Sir Francis Spring, the chairman of the Madras Port of Trust. Afterwards it became easy for Ramanujan to secure recognition of his work.

Griffith reached out to his former professor of twenty years, Micaiah John Muller Hill, asking him to determine if there is any brilliance in Ramanujan's work. In reviewing Ramanujan's work, he indicated that, "he [has] fallen into some pitfalls; some of his results were simply absurd and should he wish to overcome his evident deficiencies, he should consult Bromwich's Theory of Infinite Series Test". Hill wrote again to Griffith, without answering the question, but this time with more encouragement saying, "Mr. Ramanujan is evidently a man with a taste for mathematics, and with some ability." He went on to write, "his educational deficit was hurting him, and many mathematicians of earlier days stumbled over these duties, so it is not surprising that Mr. Ramanujan working by himself has erroneous results. I hope he will not be discouraged." He did not offer to take Ramanujan on as a student (Kanigel, 1992).

Ramanujan was encouraged by Seshu Aiyar, Sir Francis Spring, and others to correspond with universities who may take an interest is his work, and they helped him draft letters to University of Cambridge, providing them with samples of his work. He wrote to H. F. Baker, a distinguished mathematician and a fellow at the Royal Society who had been president of the London Mathematical Society. Baker returned his work without comment and declined to take him on as a student. Ramanujan wrote to W. E. Hobson, a mathematician and a fellow of the Royal Society that held Cambridge's Sadleirian Chair. Like Baker, Hobson also declined (Kanigel, 1992).

3.6 Getting Noticed

On January 16, 1913, Ramanujan wrote G. H. Hardy, a young mathematician at Cambridge that was making the world of mathematics take notice of his work, to send him 120 theorems as a representative sample of his work. Hardy reviewed

Ramanujan's samples and then he wrote back acknowledging he knew some of the theorems; others looked new and he could work through them; and there were some that were beyond his understanding. Hardy shared the sample work with his colleague John Edensor Littlewood, asking him "Genius or fraud?" After examining the theorems, Hardy wrote, "these could only be written down by a mathematician of the highest class", to which Hardy added "They must be true because, if they were not true, no one would have the imagination to invent them".

Hardy arranged for the University of Madras to give Ramanujan a scholarship and invited him to travel to England; Ramanujan initially declined even though he had his friends, influential people, and even the orthodox Brahmins urging him to cross the oceans to England. It was only after his mother proclaimed, she had a dream where the goddess Namagiri was commanding her not to stand in her son's fulfillment of his life's purpose, when Ramanujan departed India on March 17, 1914 arriving in Cambridge on April 30, 1914 (Kanigel, 1992).

Immediately, Ramanujan's collaboration with Hardy led to new mathematical developments. Ramanujan's lack of formal education would lead him to make mistakes that have since been overcome with modern mathematics. Littlewood was asked to teach Ramanujan modern mathematics, but he found it was extremely difficult because every time some matter, which it was thought that Ramanujan needed to know, was mentioned, Ramanujan's response was an avalanche of new original ideas; this made it almost impossible to teach modern mathematics to Ramanujan (Kanigel, 1992).

Ramanujan was an orthodox Brahmin and a strict vegetarian; once a fellow Indian joked that the potatoes he was eating from the college kitchen were fried in lard; true or not, Ramanujan never ate food from the college kitchen again. Ramanujan started cooking his own food in his room and only using a pot that was never in contact with meat. When Ramanujan did eat, he did not always get the nourishment he needed, which could have made him more susceptible to illnesses. In March of 1915, Ramanujan was ill due to the winter weather and could not publish anything for five months. While he continued to work, the volume of work declined due to his illness.

In 1915, Ramanujan's paper on *Highly Composite Numbers* was a significant contribution to mathematics appearing in the Proceedings of the London Mathematical Society. In 1916 Ramanujan and Hardy published the *Asymptotic Partition Formula* where they developed a formula to determine the number of partitions for number n expressed as $p(n)$. For example, the number of partitions for $n = 4$ were $p(4) = 5$, listed as

$$4 = 4 \tag{3.2}$$
$$= 3 + 1 \tag{3.3}$$
$$= 2 + 2 \tag{3.4}$$
$$= 2 + 1 + 1 \tag{3.5}$$
$$= 1 + 1 + 1 + 1. \tag{3.6}$$

To test their formula, they enlisted the help of Percy Alexander MacMahon, another mathematician at Cambridge known as the calculator. Ramanujan asked MacMahon to calculate the number of partitions of 200, it took MacMahon about one month to determine there were 3,972,999,029,388 partitions. There was only a relative difference of 0.004 in the value calculated using the formula. In March of 1916, Ramanujan was awarded a bachelor's degree from Trinity College for his contributions to mathematics (Kanigel, 1992).

3.7 Beginning Of The End

At beginning of 1917, Ramanujan became very ill, and many of his doctors thought he would die soon; spending most of the year in bed, he continued to work. Ramanujan showed some improvement in his health by September of that year but remained in bed most of the time. Hardy, fearing Ramanujan's death and willing to recognize his contributions to mathematics, approached the Cambridge Philosophical Society and the Royal Society of London making a recommendation along with supporting recommendations from other mathematicians including MacMahon, Grace, Larmor, Bromwich, Hobson, Baker, Littlewood, Nicholson, Young, Whittaker, Forsyth and Whitehead, to make Ramanujan a fellow. On May 2, 1918, Ramanujan was elected fellow of the Royal Society of London, and on October 10, 1918, he was elected a Fellow of Trinity College Cambridge—he then had the right to walk on the grass in the college courts. The recognitions given to Ramanujan raised his spirits, and his health improved a little; he renewed his efforts in developing theorems (Kanigel, 1992).

Ramanujan left Cambridge in February 1919 returning to India; during his voyage home and in the subsequent year his health began to deteriorate. Many of his influential friends came to his aid, providing Ramanujan with the best doctors and medical care, but his condition continued to deteriorate. As his health declined, his visions from the goddess Namagiri kept coming to him and he wrote them down on sheets of paper while he was rarely resting. It was as if Ramanujan knew his life was coming to an end. He began to work fanatically during the last four days of his life. He asked his mother to collect all his notes, put them in a box and to send them to Hardy in Cambridge so that his theorems would not die with him. On the morning of April 26, 1920, Ramanujan fell into a coma and died in the afternoon (Ono and Aczel, 2016).

If we were to only examine Ramanujan's contribution to mathematics, it could only be described as astonishing. That only tells you of his accomplishments and nothing about the man and his struggles in life. Ramanujan survived diseases and famine that killed hundreds of thousands during his lifetime. He taught himself mathematics from a young age, scoring first in the school district; yet, sadly he failed to graduate. He grew up in poverty not having enough money to eat or even buy paper for his notes, so he often used chalk to write his formulas on the ground. Yet through all of this adversity and with the help from some friends to get him noticed at Cambridge, he leaves us with theorems that we are only starting to understand today. Ramanujan was and continues to be a remarkable mathematician (Ono and Aczel, 2016).

"An equation means nothing to me unless it expresses a thought of God."—Srinivasa Ramanujan

4 Muhammad ibn Musa Al-Khwarizmi (c.780-c.850)

The Father of Algebra and Algorithm

By Matthew Tam, Victor Huong, Hashim Al-Hashmi, Sean Usher, and Daquan Barrow

Society continues to develop and advance rapidly, but it is only able to do so because of the foundation of knowledge that has been built by past scholars. These influential figures provided the fundamental building blocks that evolved into the current fields of science, technology, engineering, and mathematics. It should be noted that without the contributions of these scholars, the world as it is currently known would never have come to exist. Therefore, it is important to gain an understanding of these scholars in order to evaluate their impact on the development of society.

4.1 The Birth of Algebra

Of these numerous past scholars, Muhammad ibn Musa Al-Khwarizmi was an Iranian mathematician that was considered to be one of the greatest minds of his time. The exact details of his birth have been lost, but it is assumed that Al-

Khwarizmi was born in approximately 786 AD to a Persian family in the Abbasid dynasty (Leaman, 2006). Given the distinction of the epithet "Al-Khwarizmi", he is thought to have been born in Khawarizmi. However, a historian named Al-Tabari identified Al-Khwarizmi with an additional epithet of Al-Qutrubbulli and this indicates that he was actually from Qutrubull (van der Waerden, 2013). In 813 AD, Al-Ma'mun became the sixth Caliph of the Abbasid dynasty and subsequently invited Al-Khwarizmi to become a member of the House of Wisdom. The House of Wisdom was a form of accredited academy for scholars in Baghdad that acted as the centre for knowledge (van der Waerden, 2013). It was during his time in the House of Wisdom that Al-Khwarizmi gained the necessary knowledge and resources to develop and produce several groundbreaking pieces of work. Under the patronage of Al-Ma'mun, Al-Khwarizmi wrote several works that helped contribute to the modern day fields of *algebra*, *algorithms*, *geography*, and many others. Al-Khwarizmi became one of the first scholars to produce works on the problems of *Al-jabr* and *Al-muqabala* (van der Waerden, 2013). This was documented in his translated book titled, *The Compendious Book on Calculations by Completion and Balancing*, which was also translated in Latin to *Liber Algebræ et Almucabola*. It is from this translation that the word *Algebra* was derived and the subsequent identification of Al-Khwarizmi as the father of algebra. Al-Khwarizmi also wrote about arithmetic and popularized the use of Hindu-Arabic numerals after his work was translated in Latin to *Algoritmi de numero Indorum* (van der Waerden, 2013). This Latin translation rendered Al-Khwarizmi's name as Algoritmi and resulted in the term "Algorithm". Therefore, it can be seen that Muhammad ibn Musa Al-Khwarizmi was an influential scholar of the past that laid the foundation for modern mathematics and engineering.

Al-Khwarizmi is most renowned for his work in algebra that involves methods and solutions for solving linear and quadratic equations. Al-Khwarizmi often uses examples through text and pictures to demonstrate how his solutions work. This was done in part because the era of algebra was only starting to sprout and modern notations for mathematical equations had not yet been invented. It is important to note that the foundation of algebra began a movement away from traditional Greek mathematics, which focused on geometry, and used numerical equations with numbers and expressions to explain mathematical concepts. Al-Khwarizmi is the first author to write about solving mathematical problems using "Al-jabr" (later known as algebra) and "Al-muqabala". Al-jabr is the process of removing negative units, roots, and squares from an equation by adding the same quantity to each side. For example, the following operation uses the process of Al-jabr'

$$x^2 = 30x - 4x^2 \to 5x^2 = 30x. \tag{4.1}$$

On the other hand, Al-muqabala is the process of bringing quantities of the same type to the same side of the equation. For example, the following operation is the process of Al-muqabala

$$x^2 + 14 = x + 5 \to x^2 + 9 = x. \tag{4.2}$$

It is evident that the process of Al-muqabala already staisfies the process of Al-jabr. In the book, *The Compendious Book on Calculation by Completion and Balancing* written by Al-Khwarizmi, he describes how to solve simple quadratic and linear equations using what he called the solution of six types (van der Waerden, 2013). The types are as follows:

1. Squares equal roots: $ax^2 = bx$.

2. Squares equal number: $ax^2 = c$.

3. Roots equal number: $bx = c$.

4. Squares and roots equal number: $ax^2 + bx = c$.

5. Squares and number equal roots: $ax^2 + c = bx$.

6. Roots and number equal squares: $bx + c = ax^2$.

It can be jarring and difficult to understand what Al-Khwarizmi meant by this. However, historians and biographers were able to interpret the meaning of these six types. If we were to look at a simple algebraic expression for example, $ax^2 + bx + c = 0$, the first term is represented as "square" in Al-Khwarizmi's methodology, "roots" would be bx, and finally number is represented by c in today's algebra. By following Al-Khwarizmi's methodologies, one would be able to solve all of the types of equations including the quadratic equation. The difference between Al-Khwarizmi's work and other mathematicians during his era is that he ensured that an organized and procedural approach was used to find solutions to equations, which is much more akin to what we have today. Without Al-Khwarizmi, the foundations of algebra would have not been laid out in a system that is fluid and easy to interpret. If there is one thing he should be remembered for, it is that he was one of the brilliant minds of his generation that was responsible for the beginnings of algebra, a tool we use centuries later.

Additionally, Al-Khwarizmi's contributions to mathematics were not entirely focused on algebra as his practices lead to simplifying the art of multiplication. In mathematics, multiplication is filled with countless methods and tricks which are implemented for simplicity in calculations. One of those methods was developed from Al-Khwarizmi's work and it is known

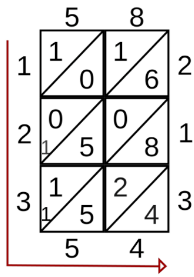

Figure 4.1: Lattice Multiplication method.

as the lattice (or sieve) multiplication method. It is defined as a method for multiplying large numbers as it is generally noted as algorithmically equivalent to long multiplication. Overall, in today's age, this historical method still poses significance in diverting the education of long multiplication. A general presumption on how the lattice method is portrayed in Fig. 4.1 that demonstrates $58 \times 213 = 12354$.

This method is simpler than perceived, as it consists of simple multiplication and addition operations throughout the diagonal channels. Firstly, a grid is drawn with diagonal lines intersecting each square. Once the template is laid out, a multiplier is set along the top columns (58), and the other one along the right of the rows (213). Next, each integer is multiplied with the aligned integer from the other multiplier with the respective answer placed in between the intersecting squares (e.g. $8 \times 2 = 1/6$). Finally, the addition procedure is implemented on the diagonal columns, which are actually inclined columns, starting from the bottom right column of the grid (e.g. $4 = 4$, $8 + 2 + 5 = 15$, ...). Values calculated from adding those columns are placed along the bottom left of teach column, with the tens carried always to the left column. The final result of the lattice procedure is read off down from the left (123), and across to the right from the bottom (54) to give 12354. Further, this method was popularized and introduced to the world by Leonardo of Pisa (commonly known as Fibonacci). However, Al-Khwarizmi's work has not been forgotten as his Latin name gave rise to the term "Algorithm".

4.2 The Birth of Algorithm

An algorithm is a mathematical procedure depicting a solution to a problem. Al-Khwarizmi used algorithms to illustrate his algebraic solutions. The development of algebra began with the Babylonians as opposed to Greeks who followed a more geometric approach. The Babylonians used geometry and algorithms to develop the "geometric algebra". As time progressed, algorithms were transformed into an "equation solving" recipe that was not justified or formed using geometry. In approximately 825, Al-Khwarizmi wrote what is now defined as the first true algebra text. Within his treatise, *The Compendious Book on Calculation by Completion and Balancing*, Al-Khwarizmi uses algorithms to present his findings and defines six types of equations that solve linear and quadratic problems. The algorithms depicted in the text are verbally based, no symbols are used within their expression. Alternative to the Babylonians, Al-Khwarizmi only expected the reader of his text to use the algorithm developed, not the geometry used to justify the algorithm. Al-Khwarizmi presented his findings mainly using abstract problems unlike the Babylonian mathematicians before him who utilized problems that contained widths and lengths.

To solve his abstract problems, Al-Khwarizmi would first simplify them and then apply the algorithm he developed. Al-Khwarizmi shifted algebra from a geometric base to a static equation base for solving problems (van der Waerden, 2013).

Comparatively, Golden Age mathematicians in the middle east, who developed their papers after Al-Khwarizmi, justified their math by simplifying their problems and then using an algorithm to find the solution. The algorithms used by Al-Khwarizmi, his Babylonian and Greek predecessors, and Golden Age successors are limited, as they are unable to solve equations that have a degree higher than two. Historians have argued that Al-Khwarizmi used Hindu, Hellenistic, post-Hellenistic, or Greek sources to assist in developing his algebraic work (van der Waerden, 2013).

4.3 Work on π

Al-Khwarizmi referenced a value for π within one of his books on astronomy that equates the estimate of π derived by Aryabhata, a Hindu astronomer, to sixty two thousand eight hundred and thirty-two divided by twenty thousand, which calculates to (van der Waerden, 2013)

$$\pi \sim \frac{62832}{20000} = 3.1416. \tag{4.3}$$

Al-Khwarizmi also referenced a value for π in his book that elaborated on Hindu-Arabic numerals. Although his original text has been lost, a Latin translation of his book was created and titled, *Algoritmi de numero Indorum*. It should be known that the Latin transcriber translated Al-Khwarizmi's name as "Algoritmi" which gave birth to the word "Algorithm". Al-Khwarizmi's work on Hindu-Arabic numerals has been conceived as being the source that spread the Hindu-Arabic numeral system across Europe and the Middle East. Europeans and Middle Easterners were able to read Al-Khwarizmi's work on Hindu-Arabic numerals after his book had been translated into various languages. Al-Khwarizmi also estimated the value of π to be approximately three plus a decimal value of one divided by seven (van der Waerden, 2013)

$$\pi \sim 3 + \frac{1}{7} = 3.1429. \tag{4.4}$$

Both Persian and Hindu sources were used by Al-Khwarizmi when he was developing his astronomical tables. Centuries later, Al-Khwarizmi's algorithmic proofs are still being used to solve algebraic problems. The algorithms Al-Khwarizmi developed created a foundation for future mathematicians to use and help solve complex problems up to a degree of the second order.

4.4 The Advancement of Geography

Al-Khwarizmi is a multifaceted scholar who indulged in the sciences that intrigued him during his era. Al-Khwarizmi is mostly known for his development of the algebraic foundations, but he also used his advanced knowledge in other areas of study such as geography. Throughout human history most societies wanted to know their bearings in relation to other places. In the Golden Age of Middle East, concurrent to the Middle Age in Europe, geography was defined as the study of places and the relationships between people and their environment; it was given little attention as a major academic pursuit in Europe. However, scientists from the Middle East and North

Africa in the Golden Age were making headway in advancing the field. Caliph Al-Ma'mun, who greatly encouraged the development of science and philosophy, played a key role in this development as he amalgamated a large number of geographers, who were led by Al-Khwarizmi. This group of scholars worked on many projects that included the determination of the circumference of the earth and making one of the most detailed maps of the known world for their time (Karagözoğlu, 2017).

Al-Khwarizmi had access to a wealth of texts as a scholar of the House of Wisdom and had taken note of texts written by Claudius Ptolemy. Ptolemy was a distinguished Greco-Roman scholar that made movements in the fields of astronomy and geography during his time. Al-Khwarizmi would later use Ptolemy's work on geography as a template to create his very own book by the name of *Kitab Surat Al-Ard*, which translates to *The Image of The Earth*. In this book, Al-Khwarizmi arranged his work using the Greek system of the seven climes to present his data (Karagözoğlu, 2017). For example, one of the climes would be dedicated for cities, and Al-Khwarizmi would provide a list of coordinates, longitudes and latitudes, for these cities. The climes he chose to present data for were the cities, mountains, seas, islands, the central points of various geographical locations, and rivers. The list consisted of approximately 2402 coordinates in total. Despite his reputation as the "father of Algebra", Al-Khwarizmi was a true geographer as he sought to understand where things were found, why they were there, and how they changed over time. Al-Khwarizmi's work created a stepping stone for future geographers and mathematicians to revise the coordinate system and maps to the point where we have a better understanding of our surrounding areas today.

4.5 Foundational Achievements

Al-Khwarizmi's greatest contribution to society is his book, *The Compendious Book on Calculation by Completion and Balancing*. This book contains the very beginnings of algebra and is paramount to the development of many technologies today. It is also worth considering that the algorithm, originally developed by Al-Khwarizmi, is the foundation on which all computer software are built and used by almost everyone today, more than 1000 years later. As far as other disciplines go, Al-Khwarizmi has imprinted his legacy in mathematics, astronomy, and geography. Therefore, it can be seen that Al-Khwarizmi is one of the many past scholars that helped build the foundation of knowledge and will be forever regarded as one of the greatest minds of mathematics.

5 Leonhard Euler (1707-1783)

A Gifted Mathematician

By Luc Carney, Kyle Friesen, Victoria Golebiowski, and Jeffrey Horbatuk

Over time many incredible contributions have been made by a variety of math and science pioneers. One of these outstanding pioneers, who stands out among others as having made such a wide variety of contributions to basic theories, methods, and experiments, is Leonhard Euler. Some of his famous contributions, gifts, and discoveries will be discussed in this biography. Euler was a mathematician who will never be forgotten and one who is definitely a role model for researchers everywhere.

5.1 Background

Euler was born in the year 1707 in Basel, Switzerland, and studied with the famous Bernoulli family and under Johann Bernoulli at Basel University. Euler found it difficult to find the appropriate recognition for his breakthroughs that he deserved since he was in the shadows of the Bernoulli family. For this reason, Euler spent much of his academic life in Russia and Germany instead. As a mathematician that had an interest in almost all topics; his collection of work reached almost 900, many of which were not published during his lifetime. By the time Euler reached the age of 68, he is said to have produced approximately one mathematical paper every single week. Euler lived until the age of 76 years old when he unfortunately died from a brain hemorrhage. Although Euler is remembered as a brilliant mathematician, his life was not always positive. In the year 1771, Euler was faced with a tremendous tragedy, a house fire, where he lost his wife and his house. Euler proceeded to marry his half-sister in law and this marriage would last until his death. In addition to the tragedy of his house fire, Euler also became blind in his late years which would of course become a challenge to his life of studies.

5.2 Early Career: The Transfer to the Academia

After his time spent learning from Johann Bernoulli at the University of Basel, Euler had decided to take on mathematics as a career. He applied for a position at the University of Basel, backed with the support of Bernoulli (Assad, 2007). However, when he asked to meet with the chair of physics at Basel, he was denied (Assad, 2007). Likely feeling disrespected, this discouraged Euler from considering the position he had applied for. At this time, Johann's sons, Nicolaus and Daniel Bernoulli, had moved away to St. Petersburg in order to join the Russian Academy and were encouraging Euler to join them. Euler had become quite close with the brothers during his learnings with their father, thus enhancing the appeal of this option. His decision was solidified when the brothers were able to offer a position in physiology at the Russian Academy (Assad, 2007).

This move helped further his career as it established his reputation as a mathematician in Europe (Assad, 2007). Euler would work and live with Daniel for six years in St. Petersburg before Daniel would decide to return to the University of Basel (Assad, 2007). This would result in Euler becoming the chair of the mathematics at the Academy. During these years, Euler would go on to do important research that would be the foundation of his legacy. The first big milestone Euler would overcome would be to solve the Basel problem (Assad, 2007). This problem was made famous by the Bernoullis for its difficulty, as Johann was only ever able to define bounds for the series of the sum of inverse square of integer numbers, but, however, he was never able to solve it. Surpassing his former professor, Euler was able to find a solution to the series, thus further disguising himself amongst his colleagues in his respective field. The series and its solution are given by

$$\sum_{n=1}^{\infty} \frac{1}{n^2} = \frac{1}{1^2} + \frac{1}{2^2} + \frac{1}{3^2} + ... = \frac{\pi^2}{6}. \tag{5.1}$$

5.3 Early Career: Ship Building

Euler's first major area of contributions was in the ship building field where he focused on survivability and safety of ships. Euler's studies in ship building are actually related to rigid body studies. In the year 1765, Leonhard published *Theoria motus corporum solidorum seu rigidorum* or *Theory of the motion of solid or rigid bodies* (Marquina et al., 2016). This publication describes the way in which Euler speculated that the motion of a ship could be described by a translational force along with a rotation about an axis that passes through the ship's center of gravity (Calinger, 2015). Since Newton had already introduced the law of motion describing the translational force, Euler identified that a similar law would need to exist for the rotational force. After much calculation and theoretical application, the "Euler equations" were published that describe the rotation of a rigid body, using a rotating reference frame with its axes fixed to the body and parallel to the body's principal axes of inertia.

5.4 Mathematical Contributions

Euler was very clearly a gifted individual who possessed both a photographic memory along with sharp mental calculation skills. Some of Euler's contributions or popularizations within the specializations of mathematics were critical for internationalization, which lead to collaboration globally for all types of problems. Some of these popular notations include e, the base of the natural logarithm, the imaginary unit i, which represents imaginary numbers, $f(x)$ or the function of some variable x, and $\sum x$, the sum of some numbers or expressions. He also popularized the use of constants for example a, b, and c in a triangle to represent side lengths or angles. In addition, Euler spent much of his time focusing on trigonometric functions and therefore popularized the use of sin, cos, tan, cot, sec, and csc among others. Finally, Euler also contributed to a major mathematical symbol known by almost all people of the world, π, which is the ratio of a circle's circumference to its diameter. Among all of these foundational findings and contributions, Euler can be identified easily by the popular "Euler formula". The formula is written as

$$e^{ix} = \cos(x) + i\sin(x). \tag{5.2}$$

This formula describes a relationship between trigonometry, exponentials, and complex numbers and is used vigorously in calculus, quantum mechanics, fluid dynamics, and in fact all of physics. However, Leonhard Euler did not stop there. In addition, another mathematical equation known as the "Euler Identity" exists and can be written as

$$e^{i\pi} = -1. \tag{5.3}$$

This identity is described by many to be an amazing and explosively beautiful composition of arithmetic, calculus, trigonometry, and complex analysis, which combines many of the mathematical notations described earlier.

Leonhard Euler was an extremely talented and gifted mathematician who made incredible and significant contributions to mathematics. The topics of Euler's contributions in mathematics have a large span encompassing areas such as analysis, number theory, topology, combinatorics, graph theory, algebra, and geometry. When speaking in terms of applied mathematics, Euler made significant contributions in the topics of mechanics, hydraulics, acoustics, optics, and astronomy. Euler is known to have made so many contributions to the fundamentals of so many subjects, that is actually rare to find an area of study which he did not contribute to.

5.5 Vision Loss

One of the most impressive aspects of Euler's accomplishments was how he overcame the limitation of his blindness. During his time researching the cartography of Russia, Euler came down with a nearly fatal fever that years later would lead to the loss of sight in his right eye. Despite being partially blind at this point in his life, Euler did not let this slow him down as he became extremely involved with the observational astronomy at the Berlin observatory. It wouldn't be until 1771 when Euler would become completely blind due to complications from a surgery. This too proved to be nothing more than a slight inconvenience as he learned to cope with his blindness. Johann Bernoulli once wrote the following about Euler describing how he overcame this new limitation: "... it is true that he cannot recognize people by their faces, nor read black on white, nor write with pen on paper; yet with chalk he writes his mathematical calculations on a blackboard very clearly and in rather normal size; these are immediately copied by one of his adjuncts, Mister Fuss and Golovin (most often the former), into a large book, and from these materials are later composed memoirs under his direction." Using this method, Euler was able to write as many articles as when he had full eyesight.

5.6 The Gentleman

Euler had a calm and peaceful mind although he was confident in his abilities in the respective fields. Humble in nature, he would often pay his respects to his predecessors by acknowledging their previous work, even if he significantly disapproved upon their work (Assad, 2007). Euler enjoyed the scientific advancements that were made by him and his fellow colleagues as he took great pleasure in familiarizing himself with their research. Euler showed great respect for his associates, as he once delayed publishing his early findings in order to allow his associate, Langrange, to take full credit for the use of superior methods (Assad, 2007). Euler had a thirst for knowledge that could not be quenched thanks to his seemingly limitless memory. His mind was so impressive, he was capable to sum complex series to the 17^{th} term all in his mind. He would even be able to memorize numerous numbers and their several respective decimal figures. Euler's memory excelled in both visual and aural aspects, as he was able to recite the entire novel of Virgil's Aeneid since early in his youth (Assad, 2007). Beyond having a great mind, Euler was a family man. He was able to peacefully work while amusing all of his children without any sign of impatience (Brüning, 2008). At any time, he could stop what he was doing in order to address his children, partake in a completely different activity, and then be able to return to his work, as if he was never interrupted (Brüning, 2008).

5.7 To the Very End

Euler had a passion for science that did not dwindle with age. Days away from death, he suffered from vertigo, yet continued to calculate the motion of balloons. Euler passed away from intracerebral hemorrhage during a heated conversation about the newly discovered planet, Uranus (Assad, 2007). Almost comedically, his last words were "I am dying". Despite the misfortune of losing such a brilliant mind, it is comforting to know he died the way he lived, doing what he loved.

5.8 True Balance

Euler's influence on modern day mathematics and physics is immeasurable. The hundreds of articles he has published have been used to guide the next generations of mathematicians, scientists, and engineers. Leonhard Euler popularized the use of notations such as e, the base of the natural logarithm, the imaginary unit i, $f(x)$ or the function of some variable x, and

$\sum x$, or the sum of some numbers or expressions. Euler was able to overcome many challenges such as his blindness in his later years without the sacrifice of productivity nor quality. Described as being calm and well-tempered, Euler treated those around him kindly and with respect. This goes for his fellow colleagues as well as his family, with the former being very precious to him. Above all, Euler took a pleasure in his work that transcended time, as he continued his work till his very death. Leonhard Euler left behind an irreplaceable legacy and many contributions to the fundamentals of various math and science disciplines that proved to be necessary for future advancement.

6 Adolf Eugen Fick (1829-1901)

Founder of a Timeless Law

By Alex Nauta, Jacob Karl, Brett Clarke, and Maria Bovtenko

6.1 Life and Achievements

Adolf Eugen Fick was a German-born physiologist who revolutionized the fields of cardiology and medicine over the course of his life. Fick is widely respected in the scientific community due to his well-known Laws of Diffusion, which partly state that the gaseous volume of flow moving across a fluid plate is related to the surface area, thickness of the plate, and the difference in partial pressures between both sides of the plate.

Born into an immensely successful family in Kassel, Germany, in 1829, Fick's father was a municipal planner, with one brother working as a professor of anatomy and another as a professor of law at the University of Marburg, where Fick first pursued his studies. The youngest of nine children, Fick was raised as a Protestant, with no specific church affiliation. This upbringing resulted in Fick having a strong moral code of conduct, which served him well throughout his professional career. Marrying Emilie von Coelln in 1862, Fick would father five children, two of whom would die at birth. At the advanced age of 70, Fick retired, but it would be short lived and a few years later in 1901, he passed due to cerebral hemorrhage. Scientific endeavours appear to run in Fick's family, as his nephew with the same name would eventually invent the contact lens.

Fick started off his career in the broad field of physiology, applying mathematics and physics, much like his father and brother, before realizing he had an affinity for the medical field. An individual who had a profound influence on impacting Fick's career path was his teacher at the University of Marburg, Carl F. W. Ludwig. Ludwig would teach over 200 medical science students over the course of his career and would work together with Fick throughout his professional life (Vandam and Fox, 1998).

Fick greatly benefitted from the generation he grew up with, as Otto von Bismarck had recently unified Germany as a single state, greatly increasing the spread of knowledge and sense of national pride in technology and science. The stability offered by this central government allowed for an era of rapid innovation, ushering in the Industrial Age, as Germany was now a single entity that could interact with, and receive ideas and information from, other Western countries such as Britain or France.

After leaving the University of Marburg, Fick relocated to Berlin in 1849, where he advanced his medical knowledge by listening to industry titans such as Johannes Schonlein and Bernard Langenbeck. Coming back to Marburg in 1851, he received an M. D. degree for a dissertation on the optic tract (Vandam and Fox, 1998). Following this, he replaced Ludwig as Chair of Anatomy and Physiology in Zurich for a short period of time, eventually ending up in a related role in Wurzburg for 31 years (Vandam and Fox, 1998).

6.2 The Columbus of Cardiology

While Fick was a talented physicist and mathematician, he was also responsible for numerous key advancements in cardiology that greatly improved the discipline's precision and methodology through adoption of instrumentation and theory practiced in physics. Fick, coming from a long line of scholars, dedicated his life to the understanding of problems found at the crossroads between physics, physiology, and medicine. His personal monograph *Medizinische Physik* stated his personal interest in the fields ranging from molecular physics to optics; his keen analytical mind and strict adherence to physical laws allowed him to acquire great success in these fields.

Perhaps most famously, Fick is known as the first person to determine the cardiac (ventricular) output of the heart, which is equivalent to the amount of blood flowing through the lungs, now called Fick's Principle. Even more extraordinary was that he determined this relation purely through deductive reasoning and a firm understanding of the law of conservation of mass. Strangely, he did not provide experimental proof to support his famous statement, and it took until 1930, sixty years after its enunciation, for the principle to be immutably proven. With his strong aptitude for math and physics, Fick was able to determine scientific truths far earlier than any of his peers (Shapiro, 1972).

Fick's Principle, while developed almost 150 years ago, continues to have a profound impact on the field of cardiology to this day, where it is enormously useful in determining blood flow through an organ. But his pioneering breakthroughs were not solely limited to hemodynamics; his gift for mathematical-physical thinking also enabled breakthroughs in the mechanics of the musculo-skeletal system. He was particularly interested in the origins and nature of body heat generation and frequently sought to determine the substance responsible for supplying the muscles with chemical energy. During experimentation, he carefully measured the heat generated through muscle contraction, and developed the terms isotonic and isometric to help describe the process of muscular contraction. As a result of his efforts, he was able to conclude that chemical energy was directly converted to kinetic energy and that the strength of muscle contraction was a function of the length of the muscle fibre (Shapiro, 1972). By the end of his 47-year career, Fick studied the physiology of muscles, resulting in an extraordinary 37 papers as well as 16 doctoral dissertations on the subject (Shapiro, 1972).

While Fick was a prolific publisher and researcher of the mechanics of the skeletal system, he was also well known for his pioneering work in numerous areas related to medical physics. Working in the same vein as other giants of his time such as Carl Ludwig, and Hermann von Helmholtz, Fick made groundbreaking progress in the development of medical instrumentation. He developed a plethora of medical measuring devices such as the pneumograph and an improved aneroid manometer (Shapiro, 1972). Also, he developed the Imbert-Fick law, which related the deformation of the cornea to intra-ocular pressure, which led to the development of the first practical device for measuring intra-ocular pressure.

6.3 Climbing to the Top of His Field and the Top of a Mountain

A physicist, a cardiologist, and a mountain climber, in 1865, Fick along with fellow professor Johannes Wislicenus would seek out to determine what fuels the human body, and how better to do it than to climb a mountain in Switzerland. The hypothesis they sought to prove was put forth by chemist Justus Liebeg in 1842 and stated that proteins alone powered muscle contractions (Heggie, 2016). In this model, during exercise muscles were powered by chemical reactions that broke down the muscles and liberated energy, which was converted into movement and heat, and the muscles were then rebuilt during rest periods.

During this turbulent time in Europe, many nations were concerned with how to keep their populations and soldiers fuelled and fed to increase economic and industrial output. Liebeg's theory was heavily supported by anecdotal evidence and inferred knowledge; it was widely known and published that high protein diets resulted in higher energy and were widely used by athletes of the time to increase performance.

By 1865, Liebeg's theory had experienced only minor challenges that published limited results due to Liebeg's influence and respect in the field. However, Fick and his partner Johannes Wislicenus were determined to challenge the theory and would choose Mount Faulhorn as their "laboratory", where they would burn calories by climbing the mountain and compare the associated energy to the protein breakdown in their bodies. "We preferred the mountain to a treadmill, not merely because the ascent is a more entertaining employment, but chiefly for the reason that we had no suitable treadmill at our disposal" (Russel, 1996).

In order to conduct their experiment, the body was looked at as a machine in thermodynamic terms with specific inputs and outputs that could be determined. If Liebeg's theory was true, the amount of protein broken down as measured by the urea content in their urine would be equal to the amount of calories (energy) used to climb the mountain, as no additional dietary protein was consumed during the ascent. The results at the end of the eight-hour climb were clear, accounting for only the minimum required calories (energy) to ascend the mountain; it was suggested that the breakdown of protein alone provided insufficient energy and the body must draw energy from another source (Heggie, 2016).

Fick's findings would have direct impacts on the scientific community as well as national policy, however not all the feedback would be positive. Well into the 1870s Fick would be criticized for his role in disproving Liebeg's theory; however, he would stand by his findings and refused to back down. More positive feedback came from the United Kingdom, where the chief military doctor would change the diets of soldiers based on their findings (Heggie, 2016).

6.4 Fick's Laws of Diffusion Still Relevant Today

Aside from Fick's physiology contributions, his arguably most well-known achievement is the development of the Fick's Laws of Diffusion in 1855 (Koiwa, 1998). It was Fick's interaction with Carl Ludwig that began his involvement with diffusion, since Ludwig, as a professor of anatomy and physiology, was interested in diffusion through membranes (Tyrell, 1964). Furthermore, Fick's work stemmed from the experimental study of diffusion that was first researched by Thomas Graham, who developed qualitative and quantitative data based on the experiments he conducted on diffusion (Tyrell, 1964). Using this data, Fick went on to uncover the basic laws that govern the transfer of material from one layer of a solvent to another (Tyrell, 1964).

Fick described the process of diffusion using two groups of molecules, one of species A and one of species B, where the attraction between two different groups of species was greater than the attraction between two of the same group (Tyrell, 1964). From placement of the two species adjacent to each other, he found that species A would be drawn to a region where species B was previously, and species B would be drawn to the region where species A was previously (Tyrell, 1964). This process would continue until both species were uniformly distributed throughout the whole region (Tyrell, 1964). Fick compared this discovery, his basic law of diffusion, to the spreading of heat in a thermally conducting material according to Fourier's Law of Conduction and electricity flowing in a conductor according to Ohm's Law (Tyrell, 1964).

After defining the basic law through his experiment with molecule species, Fick continued his work by applying this law to real systems, ultimately determining that upon mixing the volume change in the solvent can be neglected (Tyrell, 1964). From this discovery, Fick was able to narrow down that the driving force behind diffusion was not the solution density gradient, but it was the concentration gradient, known as the Fick's First Law of Diffusion (Tyrell, 1964). Furthermore, Fick did not stop there, he proceeded to focus his attention on the development of his second law, known as Fick's Second Law of Diffusion, where he would need to demonstrate that the diffusion coefficient in his equations was independent of concentration in order to confirm his law (Tyrell, 1964). He persevered and tried several possibilities until he devised a technique using a column with sodium chloride crystals at the bottom with a constant supply of fresh pure water at the top, which demonstrated that the concentration distribution at the top of the column was characteristic of a time-independent state (Tyrell, 1964). Ultimately, this determined that the concentration gradient is the ratio of the solubility of salt to the height of the column, which is only true if the diffusion coefficient is independent of concentration (Tyrell, 1964). Through his dedication and constant pursuit of scientific evidence, he was able to demonstrate that his results confirmed his second law.

In the same way that Fourier's and Ohm's laws are well used today, Fick's laws have been proven prevalent and useful in many years following their discovery. For instance, the rates of biodegradation of various hydrocarbons can be estimated from oxygen and carbon dioxide profiles, which is important in the field of bioremediation (van de Steene and Verplancke, 2006). The respiration rates of these gases can be calculated using Fick's laws, giving a description of gas diffusion processes in soil (van de Steene and Verplancke, 2006). In addition, Fick's laws may be modified in order to provide more accurate production rates of certain gases by adding a correction term for advective flux (van de Steene and Verplancke, 2006).

Fick made great contributions to the fields of medical physiology and physical science, both of which are incredibly valuable and still widely used today. Fick's laws of diffusion continue to be relevant today, as they have provided many scientists and engineers with laws that can be modified or adjusted to suit their specific applications. In addition, his findings have proven to be valuable not only in science, but they also have had impact on policies related to the health of people worldwide.

7 James Clerk Maxwell (1831-1879)

The Man Who Changed Everything

By Margaret Jasek, Allissa Bartlett, Morgen Menig-McDonald, and Katelyn Sysiuk

James Clerk Maxwell's most well-known achievement was to formulate the classical theory of electromagnetic radiation, merging for the first time theories of electricity, magnetism, and light as different manifestations of the same phenomenon. Maxwell's equations for electromagnetism are dubbed as the "second great unification in physics" after the first one credited to Isaac Newton. In this essay, however, we delve into Maxwell's work on mechanics, the study of motion of bodies, as he applied it to very large and very minuscule scales.

7.1 Early Life

James Clerk Maxwell was born in Edinburgh, Scotland, in 1831. His father was John Clerk Maxwell and his mother was Frances Clerk Maxwell. His father portrayed characteristics that were more cautious but very considerate, while his mother was known to radiate blunt determination. During his childhood, Maxwell showed many signs of intelligence early on. He was known to constantly be asking questions. His cousin remembered him often asking the question, “What does it do?” when seeing something for the first time. His aunt remembered being embarrassed by not being able to answer so many questions asked by a child. He was also known for laying in the grass, staring at the sky and simply wondering, content with the company of his thoughts (Campbell and Garnett, 1882).

When Maxwell was a bit older, he was not constantly asking questions and simply observing anymore, but he was engaged in doing and creating. This was when his inventiveness began to show itself. One of Maxwell’s caregivers, Mrs. Murdoch, gave him a tin plate to play with when he was only two and a half years old. It was noted to be a sunny day and Maxwell angled the plate to the sun and watched the reflection bounce around the room. He called for his parents to show them what he had discovered. They were delighted to see his curiosity and brilliance from such a young age and his father told him he would teach him about the moon and stars when he was older. Mr. Maxwell enjoyed teaching his son; however, it was not long until the roles were reversed (Campbell and Garnett, 1882).

Maxwell was taught by both of his parents until his mother’s death in 1839. After her passing, his father tried to bring a tutor to their home. This was determined to be unsuccessful as Maxwell’s learning was slow and the tutor was discovered to be rough and abusive with Maxwell. Even though Maxwell was known to never complain and even assured his father that everything was right, his aunt believed that he never overcame the lasting effects of the abuse. His father decided that Maxwell needed to be led, not driven, as he was getting to be more adventurous on his own. Mr. Maxwell decided that putting him in school was the best option (Campbell and Garnett, 1882).

7.2 Education and Career

Maxwell attended Edinburgh Academy from 1841 to 1847. While he attended this academy, he lived with his father's sister, Isabella Wedderburn. He took an interest in Latin, Greek Delectus, Scripture, Biography, and English. Despite being interested in these subjects, he did not get along with his school mates. They made fun of him and called him "Dafty" (dull). Even though Maxwell's father put Maxwell in this school because he believed it was best for him, he somehow had a neglect for Maxwell's appearance. The clothing that Maxwell wore to school was different than the other boys. His were comfortable and casual, unlike the other students. His clothes could be described as "rags" and he was bullied by the other students (Campbell and Garnett, 1882). Even though he was not irritated by this, this poor clothing choice could have possibly been swayed if his mother was still alive.

He spent most of his time alone wandering in nature and admiring the wildlife. However, he eventually did gain some support through a professor who was impressed with Maxwell's work, Professor Forbes. Forbes even sent a letter to his father stating, "I have looked over your son's paper carefully, and I think it [is] very ingenious" (Campbell and Garnett, 1882). Perhaps it was this supportive relationship that provided Maxwell with a mentor and helped him excel later on in life.

Maxwell simply completed his courses at school instead of skipping ahead even though he had the potential to. It was contemplated whether his inventions that he worked on outside of school interfered with his academic success during this time.

He missed the Mathematical Medal competition but proceeded to do quite well upon graduation, coming first in Mathematics and English. He also published his first paper in the Proceedings of the Royal Society of Edinburgh at the age of fourteen. Overall, he looked back on his school days affectionately. He only wished that he was not so much misunderstood by so many people (Campbell and Garnett, 1882).

In 1847, Maxwell entered the University of Edinburgh, where he studied mathematics. He struggled with socially fitting into this environment similarly to the Academy he attended. He was known to not reply directly in conversations and to speak in a monotone manner. However, university gave him more freedom to explore his interests. He focused on polarized light, galvanism, rolling curves, and the compression of solids during his time at this institution. He published a paper during this time on the equilibrium of elastic solids and the equations he derived (Flood et al., 2014).

In 1850, Maxwell enrolled at Cambridge University where he completed his bachelor's degree and later became a fellow and published his work, *Experiments on colour as perceived by the eye* (Marston, 2016). In 1856, Maxwell applied to become the Chair of Natural Philosophy at Marischal College. Even though he was young for a professor at the age of 24, he was still appointed. In 1860, he applied for a Chair position at King's College, London, and was also successful. In 1865 Maxwell resigned so he could focus on experiments and theories (Flood et al., 2014).

7.3 Rings of Saturn

The subject of the Adam's Prize in 1855 was the stability of Saturn's rings. This was a very mysterious subject, upon which many questions revolved. Astronomers had been struggling to explain this phenomenon for the previous 200 years before this competition. This problem was proven to be extremely difficult and submissions had to be in by December 1857. Just to highlight Maxwell's brilliance, although Pierre Simon Laplace was a famous mathematical astronomer he was unable to make any significant progress with this quest. He was able to show that the rings could be unstable but failed to explain how they are stable. Maxwell took a different approach and started at the centre of Saturn. He utilized two methods that already existed but the brilliant part of his method was the sequence and application in which he used them. For the first approach, he formed equations of motion, including the gravitational potential due to the rings, from the centre of Saturn. However, this resulted in one unrealistic scenario, in which the rings would be stable. This scenario included that the rings were significantly lopsided, which, as could be seen in telescopes, was not the case (Mahon, 2004).

The second method he tried was the method of Fourier. He analyzed the different types of waves that could occur. This proved that fluid rings would break up and form separate masses. By the process of elimination alongside his determination, he showed that even though the rings appear to be continuous they are not. Maxwell built a mathematical analysis of what would happen if the rings were made up of equally spaced particles. He was able to prove that some arrangements of the rings would be stable and recognized that there would be collisions between the particles. He learnt the mathematics he used in solving this question at University of Edinburgh and Cambridge University. Out of all the famous mathematicians and astronomers, Maxwell was the only one to complete this quest and submit his entry. He won the Adam's Prize (Mahon, 2004).

Instead of letting this victory take him down, as there was no other competition, Maxwell saw even more value in this win. This success helped Maxwell to build a reputation and a name for himself, and for the schools he attended during his education. He was happy with this win but even prouder that he could give back to the educational system that provided him with so much. The Voyager missions in the 1980s backed up Maxwell's theory, as particles theorized in the theory by Maxwell were proven to be made of ice and rock material (Mahon, 2004).

7.4 Maxwell's Kinetic Theory

Among Maxwell's major contributions, Maxwell built upon the work completed by Rudolf Julius Emanuel Clausius regarding kinetic theory. Clausius developed two assumptions that were essential to Maxwell's work, the first being that molecules were not necessarily elastic spheres and the second regarding the angle of reflection when particles collide. However, Clausius was unable to determine the mean free path of a molecule and therefore unable to determine its size. This is what Maxwell focused on. He studied intermolecular collisions and his work was much more complete and comprehensive than Clausius'. He used statistics and physics, and collaborated with Ludwig Boltzmann. Maxwell was able to manipulate probabilistic methods as he was familiar with them from his philosophy courses at the University of Edinburgh. His mentor and friend, Forbes, also used similar methods. Maxwell was able to complete this work because of his education and the great relationship he developed with Forbes. He also used this knowledge and built upon it when working on the question regarding the rings of Saturn. He completed his work on the rings of Saturn before working on kinetic theory, which gave him the experience and knowledge with the motion of particles that he required (Flood et al., 2014).

During his education, he was always trying to build and create experiments, which was said to be the reason why he did not reach his full potential. It was no surprise that he often turned to this approach in his later years. In 1856, he had finished a paper that contained an expression for the mean free path and a sketch of viscosity. This later led him to connect molecular motions to transport properties of gases. In order to measure the coefficient for the viscosity of air, he used an experiment. This experiment used a pendulum that was made of three horizontal glass discs clamped perpendicularly to a vertical wire. The discs rotated under various pressures and temperatures. He performed his experiment at his home so in order to increase the temperature, he had to heat his house. The contraption was protected from wind currents by using a wooden box. This experiment was performed out of curiosity. Maxwell stipulated that viscosity did not rely on the pressure of the gas, and he was proven to be correct. The results of this experiment were essential to support his further work on the kinetic theory (Flood et al., 2014).

Maxwell's work on his kinetic theory was extremely important to the development of molecular physics. His work on this topic has shown his ability to produce theories of the outmost importance and to close significant gaps that existed in the knowledge of molecular physics. A successor to Maxwell at King's College stated, "There is scarcely a single topic that he touched upon that he did not change almost beyond recognition" (Marston, 2016). His ability to do so was due to the knowledge and support he gained from his mentor, Forbes, and his excellent education. Maxwell's childhood and education shaped him so that he could change society's perception of reality. He was able to create foundations that were essential for the scientific and technological advances that proceeded. He ignited a scientific revolution!

8 Robert Hutchings Goddard (1882-1945)

Father of the Space Age

By Shauna Armstrong, Laura Bender, Hannah May, Elli Shanen, and Alana Valle

In reflecting on the motivation for his career, Robert Hutchings Goddard once said, "if a way to navigate space were to be discovered—or invented—it would be the result of knowledge of physics and mathematics ... I resolved forthwith that I would ... shine in those subjects" (Linn, 2014). Alas, this was exactly what Goddard did. Using only the basics of mathematics and physics, Robert Goddard's research on liquid-fuelled rockets became undeniably essential for the fundamentals of space travel and will continue to influence modern rocketry for generations to come.

8.1 Dreams of Space

Robert Hutchings Goddard was born in Worcester, Massachusetts, on October 5, 1882, to parents Nahum Danford Goddard and Fannie Louise Goddard. He had a brother who was born in 1894 and died that same year. Robert H. Goddard's lineage traces back to William Goddard who arrived in Massachusetts in 1665 from England. In 1924, Goddard married Esther Christine Kisk and they never had children together.

Robert H. Goddard's dream of space travel began in his early life. As a child, Goddard was often homebound due to illness, taking prolonged leaves from school. During this period, Goddard spent much of his time reading about astronomy, mechanics, physics, mathematics, the atmosphere, electricity, and science fiction. Some of his favourite pieces included H. G. Well's *War of the World* and Jules Verne's *From the Earth to the Moon*. These books sparked creativity within Goddard and set him on a path of determination to convert fiction into reality. This notion was further instilled in Goddard at the age of seventeen, while pruning the branches of a cherry tree in his family's backyard. As he cut away the dead limbs, he imagined how wonderful it would be to create a vehicle that could travel to Mars. When Goddard descended from the tree, he realized the purpose of his existence (Hunley, 1995). In the years following, Goddard visited this tree on the anniversary of his epiphany to commemorate this important turning point in his life.

After Goddard's health improved, he returned to school to pursue his education. He graduated from South High School in Worcester in 1904 at age 22 as valedictorian of his class. His address ended with the phrase "it has often proven true that the dream of yesterday is the hope for today and the reality of tomorrow", which he continued to prove true through the course of his lifetime for his advancements in rocketry.

8.2 Out of this World Ideas

In order to make Goddard's dream of space navigation a reality, the right foundation was required. Goddard attended Worcester Polytechnic Institute in Massachusetts, where he pursued an undergraduate degree in physics. Graduating in 1908, he remained at the institute the following year as a lecturer (Pendray, 1945). His studies later continued at Clarke University where he obtained his master's degree and Ph.D. in physics from 1911 until 1912 (Pendray, 1945). Goddard became a full professor of physics the year following and continued this position with the university until 1943, becoming head of both the physics and math departments during this time (Linn, 2014). Although largely based in academics, his career was not entirely spent at the institution; Goddard took many leaves of absence throughout his time to pursue his own research.

While at Clarke, Goddard's doctoral research expanded beyond space travel as he produced his dissertation titled *On the Conduction of Electricity at Contacts of Dissimilar Solids* in 1911 (Linn, 2014). However, his interest in rocketry was never forgotten and during a brief research fellowship at Princeton University in 1912, he formed the foundational computations and concepts on the practicality of rocket power by liquid fuels (Pendray, 1945). However, Goddard's research was interrupted as he ran into a significant health scare in March of 1914 (Linn, 2014). Diagnosed with tuberculosis in both lungs, Goddard was expected to die by the spring and returned to Worcester. However, Goddard survived and began a slow recovery process. It is unclear what effect this near-death experience had on Goddard and his dream of space travel, but accounts from physicians claim that they had never seen a man with such determination to live (Linn, 2014). This perseverance was likely fuelled by his determination to succeed in rocketry and with a miraculous recovery Goddard returned to his work with a drive greater than ever.

Returning to Clarke in 1914, Goddard's experiments were at the expense of his own resources and salary (Pendray, 1945). Aware of his limited funds, Goddard wrote to the Smithsonian Institute and requested $5,000 for research on the pursuit of reaching higher altitudes with weather balloons and refrained from disclosing his true goal of rocket propulsion to the moon. Unaware that the investment would lead to massive advancements for science and mankind, the Smithsonian provided this initial funding and was a continued supporter of Goddard's further rocketry research (Pendray, 1945).

Conceived in 1909 and patented in 1914, the main principles of Goddard's liquid-fuelled rocket design consisted of a multi-stage rocket with separate fuel and oxygen tanks, a high-pressure combustion chamber, and a high velocity exit nozzle. On March 16, 1926, after five years of development, Goddard launched the first liquid-fuelled rocket ever constructed (Pendray, 1945). In Auburn, Massachusetts, on his aunt's farm, the 15-feet tall rocket travelled 41 ft up into the air and 184 ft laterally until returning to earth in just three seconds. This was the first of many experimental rocket launches, which had increasing success until 1926, when Goddard was ordered to relocate by the fire marshal.

Word of Goddard's work extended beyond the academic sphere and individuals in aviation and military disciplines became interested. In 1929 Colonel Charles A. Lindbergh became Goddard's confident and his link to Daniel Guggenheim and the Florence Guggenheim Foundation (Pendray, 1945). The foundation provided $50,000 in funding for Goddard that lead to a new laboratory location in Mescalro Ranch, New Mexico, which provided ideal conditions for experimental work and for Goddard's respiratory requirements.

Goddard's research was not widely shared in literature and most of his findings were published in only two papers, *A Method of Reaching Extreme Altitudes* in 1919 and *Liquid-Propellant Rocket Development* in 1936. The former of the two explored a mathematical demonstration to show possibilities of powder or "dry fuel" rockets and included a theoretical multi-stage approach for a solid propellant rocket to reach the moon (Winter, 2016). It also included the first published proof that a rocket could work in a vacuum (Linn, 2014). The second piece was developed after extensive experimentation in New Mexico, documenting his historical first flight (Winter, 2016). Goddard's research was more than a product of his time and space, but it was fuelled by a deep driven passion and dream for space travel. Although his true goal was to reach the moon, he was not blind to social context and also applied his research to military applications.

8.3 Rockets to Weapons

Upon the outbreak of World War I (WWI), Goddard set his work regarding liquid-fuelled rockets aside to focus on weaponry. At this time, he tried to interest the army in using rockets to launch projectiles from ships rather than guns, but he was shut down by the Navy who thought development and accuracy would take too long. Instead, his main contribution at this time became the design of the hand-carried, tube-launched rocket, later to become the bazooka. Following the end of the war, he returned to his research in larger scale rocketry in the 1930s, and received many questions from German scientists. Goddard was suspicious of what the Nazis would pursue with rocketry, especially with the prospect of war on the rise. He became involved in the military once again, at the outbreak of World War II (WWII), advancing military technology by introducing the design of the jet-powered take off and rocket propulsion for aircraft.

Goddard remained very secretive throughout his career, which was largely attributed to his fear what others would develop from his published work. This fear came to life as World War II was coming close to an end. Goddard was able to inspect one of the German V-2 rockets that was captured and claimed that his designs were copied using information from his patents. The captured V-2 rocket contained all the elements of Goddard's design including the arrangement inside the shell (Winter, 2016). Although Goddard remained secretive for legitimate reasons, it is speculated that this personality trait may have hindered his success in the further development of rockets in his lifetime.

8.4 Hindered by Secrecy

Although Goddard's research played a huge role in the development of rocket technology and innovation in the military, there was significant controversy surrounding his work throughout his lifetime and to this day. Many attribute this controversy to his reserved nature and 'loner' personality. When interacting with the press and in his publications, Goddard often provided little technical details and specifics of his results (Linn, 2014). This led to a significant mistrust in the legitimacy of his work and may have hindered the actual production of the many patents and ideas he possessed. Goddard's mistrust extended even to his closest colleagues. To protect his work, he enforced that all his employed assistants in his rocketry research sign oaths to refrain from speaking of his work outside the laboratory (Winter, 2016).

Goddard had good reasons for hiding his work, as he was consistently weighed down by the gravity of the press. For example, a New York Times editorial feature released in 1920 dismissed Goddard's theory that a rocket could function in a vacuum. It stated that Goddard "did not know the relation of action to reaction, and of the need to have something better than a vacuum against which to react—to say that would be absurd. Of course he only seems to lack the knowledge ladled out in daily high schools". For Goddard, it was easiest to keep his work a secret and avoid ridicule.

Many questioned the actual importance of Goddard's work in influencing the trajectory of modern rocketry beyond an inspirational influence, as his successes were tied solely to purely mathematical demonstrations of how a multi-stage propellant rocket could reach the moon (Winter, 2016). Goddard never actually informed the press of his successful first liquid-propellant rocket flight, having kept this secret from the press for almost a decade. It was only briefly mentioned in his publication *Liquid-Propellant Rocket Development*, which included no actual engineering details (Winter, 2016). In this paper, he failed to address the problems he encountered at various steps of his work, and the engineering process he followed. This limited the paper's usefulness for others in the future to develop similar rockets (Hunley, 1995). Although this protected his work, it was one example of how he failed to allow others to learn from his work in future rocketry development. Others also attribute Goddard's failure to achieve his goal of launching rockets to truly high altitudes to his mystical belief in success of his rockets from the day of the cherry tree, and his scientific character hindered by philosophical ignorance (Hunley, 1995). His engineering methodology was centred around the belief that the universe would repeat previous configurations over many trials and that "logic is only the art of going wrong with confidence" (Hunley, 1995). This led many to believe that he lacked the scientific knowledge to perform legitimate experiments. While individuals throughout time claim he was too secretive or philosophical to achieve advancements in modern rocketry, it is undeniable that Goddard developed theories and patents used in rockets today.

8.5 Awards and Legacy

Goddard passed away on August 10, 1945, plagued by throat cancer. Following Goddard's death, his wife Esther continued to champion and support his lifetime of work, continuing his research in hopes of advancing the quest for space travel (Pobuda, 1969). In addition to conducting interviews for articles and biographies, Esther acquired the role of patenting Goddard's ideas and rocket components (Pobuda, 1969). Goddard had been officially credited with 214 patents pertaining to rocketry, of which 131 were filed by Esther following Goddard's demise.

On May 1, 1959, NASA established the Goddard Space Flight Center in Greenbelt, Maryland, its first space research laboratory (Winter, 2016). The formal dedication was held on March 16, 1961, exactly 35 years after the launch of Goddard's first liquid-fuelled rocket. Ten years following the creation of the laboratory, NASA published the history of the facility, titled *Venture Into Space – Early Years of the Goddard Space Flight Centre* (Winter, 2016). In this official document, Goddard is described as the "Father of American Rocketry" (Winter, 2016). In July 1969, NASA launched the Apollo 11 mission, using many of Goddard's principles and ideas to land the first two humans on the Earth's moon.

During his lifetime, Dr. Robert H. Goddard and his contributions to space science and engineering received recognition and many distinctions by respected scientific organizations and establishments. The appendix of the published document *The Papers of Robert H. Goddard* lists 52 awards, exhibits, and memorials awarded to Goddard after his death (Winter, 2016). Many of these recognitions were bestowed during the early U. S. space programs and the Space Race with Russia (Winter, 2016). A few months prior to his death, Goddard had been elected to the Board of Directors of the American Rocket Society, a society of which Goddard had been a member of for many years (Pendray, 1945). In 1959, the 86^{th} Congress issued a gold medal in honour to Goddard. Goddard was also a posthumous recipient of the Langley Gold Medal in 1960, a medal awarded to individuals that pursued meritorious investigations into aerodynamics and aviation. Goddard was bestowed upon with the Daniel Guggenheim Medal in 1962, a medal awarded to individuals who have made notable contributions in the aeronautics field. Other notable commemorations include the Robert H. Goddard Memorial exhibit at the American Museum of Natural History in 1948 and the issuance of an airmail stamp featuring Goddard and the Atlas rocket by the United States Government (Atwood, 1948; Wolfe, 1964).

Goddard's lifetime of work dedicated to the development of rocketry earned him many titles including the "Father of Rocketry," the "Father of American Rocketry," and the "Father of the Space Age" (Winter, 2016). Some pieces of literature such as *The Enigma of Robert H. Goddard* attempt to invalidate these claims and Goddard's impact on modern rocketry (Hunley, 1995). Although some claims may rise from evidence, in examining his career and lifetime achievements, Goddard's contributions, inventions, and ideas pertaining to the science and engineering of liquid-propelled rocketry are irrefutable.

9 Nikolai Albertovich Fuchs (1895-1982)

Days That Made A Life

By Charlotte Stoesser, Jasmine Biasi, Keegan Cleghorn, Zofia Holland, and Stephan Iskander

"The life of a man can change radically in a day" was a phrase spoken by Nikolai Albertovich Fuchs. While Fuchs said these words in reflection of the day he met his beloved wife, Marina, he had yet to unearth how true they would be proven in aspects of his life to come. The day he met Marina, the day he met conviction, and the day he met freedom, were all pinpoints in the life of Nikolai Albertovich Fuchs. His story was long and enduring and yet it was shaped profoundly by these specific days that would mark the course for the remainder of his life as a husband, father, and forefather of aerosol science.

9.1 The Day He Met Marina

It was December of 1935 on the day he met Marina Guseva. Nearly 40, this day would be the mark in time that would lead Fuchs away from his worries of a life alone. Fuchs' life before Marina arrived in it was a decent one. Born July 31, 1895 in Lantvarovo, Lithuania, while his family vacationed for the summer away from their Moscow home, Fuchs arrived as the fourth son, and would later be followed by a sister. The family was musical; Fuchs in particular excelled at the violin and it quickly became the first of his life's passions (Spurny and Marijnissen, 1998). A natural talent for the instrument led him to continue the practice and he would later play in the orchestra throughout his university and early career time. The dedication required of such a skill is one that undoubtedly instills patience. It can be said that this perhaps was the foundation for the patience Fuchs carried through his work and life later on. In 1917 Fuchs graduated from the Moscow Commercial Institute and shortly after took position as an instructor at the Moscow Institute of Chemical Engineering. This first academic position was followed by a position at Timiryazev Agricultural Academy where his interest in research was ignited. In 1932, Fuchs was invited to organize an aerosol laboratory at the Karpov Institute of Physical Chemistry in Moscow which would mark the beginning of his life's work in the field. At this time in his life, an admired friend began to regard Fuchs as Sandy, and from then on Sandy he was called by family and friends (Spurny and Marijnissen, 1998).

In the time after meeting Marina Guseva at Dom Uschenykh, a club for scientists, Sandy's routines made room for her. The nature walks he previously enjoyed on his own now included her. Both lovers of nature, the two would scour woods and fields growing Sandy's herbarium with new flowers they would discover. They would frequently dance on Saturday nights partaking in the Boston Waltz among others and often they would practice their English together. It was only but five months before they married on April 22, 1936.

In the year following their marriage, Marina and Sandy struggled to find a place to live together. Moscow at the time was a difficult place to find stay as living situations were most often in a shared state where families lived in single rooms using furniture to partition personal spaces. It wasn't until January 1937 that Marina and Sandy moved from their respective sofas partitioned behind bookshelves in their family homes to a small room of their own, and in good time as two weeks later they celebrated the birth of their son Michael, whom they called after scientist Michael Faraday (Spurny and Marijnissen, 1998). This was a time of bliss for the newlywed couple, the profound joy they both held in their new son and the success of Sandy's work in the aerosol laboratory left them content and excited in their lives (Spurny and Marijnissen, 1998).

9.2 The Day He Met Conviction

It was the April 22, 1937 on the day Sandy met conviction imparted by Stalin's government. Exactly one year from the day of his marriage and two days from receiving his doctorate degree, an officer arrived at the Fuchs home, arrested Sandy and searched the home. Calm as always, Sandy reassured his bride not to worry over the mistake and that he would be back soon, unbeknownst to him that it would be eight and a half years until he returned (Spurny and Marijnissen, 1998). Sandy had fallen victim of denouncement by a technician in his laboratory who had chosen to denounce several people at the time, including her own parents. No criminal nor political charges were laid on him but still he was sentenced to five years in prison under charges regarding "counter-revolutionary agitation" based on a habit of reciting "counter-revolutionary" poems. It was a common thing of the time to suffer this repression, as any talk sensitive to the government could lead to prosecution, but regardless of this, the shock of Sandy's sentencing left him fainting for the first time in his life (Spurny and Marijnissen, 1998).

The behaviour of Sandy in his time as a prisoner is a highlight of the most outstanding aspects of his character. He was a man of patience, a man of perspective and a man of composure. Sandy spent months after his sentencing travelling to the prisoner reform camp under treacherous conditions. The journey was a trying one, where convicts were not separated based on criminal or political crimes and gang formations left the latter group at a great vulnerability. Travelling by foot and by rail car with little air and no food, many convicts did not even complete the journey to the camp. The reflections Sandy had of this time were all formed in optimism giving testament to the grand perspective he took on life. Sandy considered himself lucky over the fact that he had been sentenced after meeting his wife and having his son (Spurny and Marijnissen, 1998). Sandy considered himself lucky to have been sentenced before the World War II (WWII) broke out as he would have likely received a longer sentence with more brutal abuse (Spurny and Marijnissen, 1998). In addition, this time in Sandy's life highlighted his composure. Here, a man who was completely innocent was on a journey with some of the most formidable men imaginable, circumstances as such are likely to evoke withdrawal or rage or frustration and yet Sandy continued forward facing whatever was ahead of him graciously. Under attack one night, Sandy fought off two criminals out to steal his shoes and trousers, the composure he showed under the attack earned him an alliance with a gang that offered him protection until his arrival at camp (Spurny and Marijnissen, 1998).

Two weeks after his arrival at camp, Sandy was summoned to return to Moscow, not as a free man but as a specialized convict in a branch of science and engineering. Still in prison, he was among a group of selected criminals who were of use to research teams. Knowledge of Sandy's work to date earned him a spot working in a special chemical laboratory. Here Sandy was given better treatment, with his living conditions including regular meals. All the while during this time, the only knowledge Marina knew of her husband's arrest was from a postcard that detailed his sentencing and relocation plan to camp. Sandy's arrival back in Moscow was not shared with Marina for a year, until the winter of 1938 (Spurny, 1998). Marina, brought in for questioning regarding her husband, patiently appeased the authorities for two days when finally they disclosed to her that her husband in fact had been returned to Moscow. It was not for some months longer that Marina was invited to finally see her husband once again and be allowed to visit him at Butyrka prison where he was being held.

9.3 The Day He Met Freedom

Five years came and went but the turn of World War II prevented any release of prisoners during wartime (Spurny and Marijnissen, 1998). Sandy was transferred to Siberia in this time but the conditions in prison were often considered more favourable than those outside of it, with consistent food and shelter, Sandy was often in better state than his family in Moscow (Spurny and Marijnissen, 1998). It wasn't until after the war, three and a half years past his initial sentence, that talk of releasing prisoners began to stir. In October 1945, Sandy was released from prison and the next radical change of his life could begin.

The remainder of Sandy's life was dedicated to two things:

his family and his contributions to aerosol science. Following his release, Sandy began work as head of a physical laboratory outside of Moscow as he was not allowed to be registered in the city. The flat he rented near work was more of an alibi than a home as he still secretly lived with his family in Moscow. Despite the pay and the long commute, Sandy was happy and could again delve into his research. Then, in late 1946 Sandy was able to return, officially, to Moscow and it was at this time he finally was able to defend his doctorate degree that he had been so close to receiving years ago. The good luck did have some struggles, though, as Sandy's criminal past haunted him from March to September 1949 wherein he was fired from his laboratory and struggled to find work even as a factory worker. Once again, the patience of Sandy prevailed and he left Moscow, exiled, but optimistic for another way. For years he worked on his aerosols book away from Moscow until the death of Stalin lead to his amnesty in 1953 when he could return as a record-free man (Spurny and Marijnissen, 1998). Back in Moscow, his professional accomplishments began to be fruitful and continued in such a manner for the remainder of his life. In 1956 Sandy published his first book *Mechanics of Aerosols* that was one of the first publications in the study of the motion and precipitation of aerosol particles. In 1958 Sandy was officially "rehabilitated" by the government and invited back to the Karpov Institute of Physical Chemistry, his place of employment prior to his arrest in 1937. In 1959 Sandy became head of the Aerosol Laboratory at the very institute. It was in this same year that he published his second book *Advances in the Mechanics of Aerosols*. Despite his personal hardships and being alienated from works he had been a part of prior to his imprisonment, such as the Petryanov filters, Sandy's patience, perspective, and composure once again led him through and realized his passion in the field (Ensor, 2011).

Marina translated all of Sandy's works, and they grew their herbarium collection, watched their son follow a career in chemistry and adopted cats. In 1977 Sandy retired to pursue his dream of publishing a collection of materials for the field of aerosol science. It was his passion to grow the field as its own field in science and better it for generations to come (Spurny and Marijnissen, 1998). Sandy spent his final days working to complete this goal and ultimately died happily on October 10, 1982 (Walton, 1983).

Nikolai Albertovich Fuchs was a man of patience and perspective that transcended not only into his life's work in aerosol science but also in the love of his many other passions: his family, music, and nature. A life filled with unexpected circumstances that tried his character did not take anything away from the man he was nor did it interfere with his determination to shape the field of aerosol science.

10 Josiah Willard Gibbs (1839-1903)

The Mind Behind Mathematical Physics

By Michael Baldaro, Rosalee Calogero, Ye Eun Chai, and Samuel Descrochers

Josiah Willard Gibbs, who believed "mathematics is a language," was an American scientist who contributed comprehensively in the field of physics, chemistry, and mathematics. Unlike other scientists, he was not an experimenter but liked to use logic and mathematics to interpret his findings and work toward the most accurate methods to prove his discoveries. With such approach, his performance led him to explore and further develop theories in science that incorporated the usage of mathematics to provide a perfect explanation. His endless passion towards mathematical physics and physical chemistry had a great impact not only in the Roaring Twenties but also in the present day.

10.1 A Portrait of Gibbs

Josiah Willard Gibbs was born in 1839, located in the city of New Haven, Connecticut (Kumaran, 2007). Gibbs was named after his father, who overly became a successful Professor of Sacred Literature at Yale Divinity School. Growing up, Gibbs was born into a well-educated family and was able to advance his studies at an early age. He received his undergraduate degree from Yale University at the age of nineteen and presented himself highly as he graduated at the top of his class at one of the best universities in the United States at the time (Kumaran, 2007). In 1861, Gibbs then went on to become the first recipient to receive a Ph.D. in engineering in the United States. He carried out his doctoral research on brakes for railway cars at the Sheffield Scientific School at Yale University, providing him with a firm platform in applied mathematics (Kumaran, 2007). To enhance his profound knowledge of mathematics, Gibbs travelled to Europe to interact and study with successful German physicists Gustav Kirchoff and Hermann Helmholz (Kumaran, 2007). These great physicists introduced and motivated Gibbs to take further studies in the field of thermodynamics. In 1869, Gibbs decided to return to Yale University and followed his father's path to become a Professor of mathematical physics in 1871 (Johnston, 1928). Gibbs' educational endeavours, without a doubt, served a platform of success and knowledge in his years leading up to his major scientific success.

During this era, Gibbs introduced his conceptual theory of thermodynamics and published two of his first papers in 1873, in the Transactions of the Connecticut Academy of Arts and Sciences (Johnston, 1928). In his first paper, he developed graphical methods on the interpretation of thermodynamic variables and represented the state of a system in two dimensional diagrams. Engineers were very interested in his theory, as Gibbs introduced a combination of pressure, volume, entropy, temperature, and energy to view the state of a system in a two-dimensional diagram, whereas engineers had only used pressure-volume representation (Kumaran, 2007). The second of his papers, introduced a geometric representation of the state of a system in three dimensions, with the aid of entropy, volume, and energy coordinates. These papers introduced new endeavours in thermodynamics and motivated Gibbs to continue his research to amuse society. Gibbs' personal ambition led to a historical contribution to society, as it had advanced scientific principles of chemistry, which are still used to this day.

10.2 A Contrast in Scientific Style

Gibbs transformed the study of thermodynamics as it once was known as the study of gases in heat and work cycles, but he overly extended it to all substances of liquids, gases, and solids. During the years from 1876 to 1878, Gibbs introduced his paper *On the Equilibrium of Heterogeneous Substance* (Johnston, 1928). This paper became Gibbs greatest influence on the development of chemistry and thermodynamics. Gibbs free energy [per mole] was formulated and became of importance in the fundamentals of chemical reactions and their potential. This developed the theory of chemical thermodynamics and the ethics of his research. Gibbs' free energy of a system can be written as

$$G(p,T) = U + pV - TS = H - TS, \tag{10.1}$$

where p is pressure, T is temperature, U is internal energy, V is volume, S is entropy, and H is enthalpy (equal to $U + pV$). Gibbs' free energy is a thermodynamic potential that enables the calculation of maximum reversible work that may be performed by a thermodynamic system at a constant temperature and pressure.

Additionally, Gibbs derived the "phase rule" in this research piece. He defined the term phase, which was stated as the "thermodynamic state" and composition of a body of solid, liquid, or vapor, without relating to its quantity. In a phase, all physical properties of a certain material would be considered uniform. This would include properties such as the density, hardness, chemical composition, and more, of the material. The introduction of this topic lead to the derivation of the actual phase rule, in which quantity is not being considered. Phases are measured in variables such as temperature and pressure. Through several assumptions and manipulations, the following equation known as the phase rule was derived. The successful formula can be given by

$$F = C - P + 2, \tag{10.2}$$

where F is the number of degrees of freedom, C is the number of components and P is the number of phases in coexistent equilibrium. Gibbs' derivation of the phase rule has become a useful tool not only in thermodynamics but also in the study of material science. It provides useful information on the occurring phase changes in a system.

Aside from thermodynamics, material science, and sciences in general, Gibbs also played a significant role in the evolution of mathematics. He was even selected as the professor of mathematical physics at Yale in 1871. Close to the end of the 19^{th} century Gibbs worked together with other scientists and mathematicians to develop vector notation, a notation in mathematics and science that is currently used in studies today. One of these people that Gibbs worked with was Oliver Heaviside, who according to Gibbs was one of the main contributors to the development of this notation. Gibbs later contributed to a book written by Edwin Bidwell Wilson called *Vector Analysis* which helped implement the notation into subjects such as linear algebra and vector calculus (Gustafson and Wilcox, 1998). Now vector notation is a widely used notation that has many applications in sciences, mathematics, and physics. Vector notation can also be referred to as Gibbs notation.

One of Gibbs' most important contributions to the world of science and mathematics was his book *Elementary Principles in Statistical Mechanics*, which is the foundation of modern statistical mechanics. In his book, Gibbs showed how the laws of thermodynamics would arise exactly from a generic classical mechanical system such as a projectile, planet, star, or galaxy. One of Gibbs' aims when writing the book was to simplify the thousands of pages of results and findings obtained previously by Clausius, Maxwell, and Boltzmann, governing the relation between thermodynamics and statistical mechanics. Gibbs book simplified statistical mechanics to a mere 207 pages and was able to fully generalize and expand statistical mechanics into what many people know today. He demonstrated how statistical mechanics could broaden the world of classical thermodynamics to systems that encompass any number of degrees of freedom. At the time when the book was written, the general understanding of nature was proposed in classical terms because quantum mechanics was not yet conceived. Even basic facts such as the existence of atoms were still a topic of discussion amongst scientists (Cercignani, 1998). Gibbs assumed the least about classical physics when writing his book, and his findings have kept their accuracy over the years, despite the turnaround of modern physics in the early 20^{th} century.

10.3 Impact on Society

Gibbs' findings did not directly influence the Roaring Twenties; however, his profound ability in using logic and developing mathematical reasoning played a significant role in the Western society and culture in the 1920s. As industries expanded during the Roaring Twenties, his method of using specific procedures to achieve the highest accuracy became important and allowed for great establishments in technology. Gibbs derivation of phase rule, the concept of entropy, and free energy were so comprehensive and practical that it could be applied to countless problems, advancing technologies such as engines for automobiles that evolved throughout the Roaring Twenties (Koenig and Swain, 1933). Not only that, such development in technology led to an overall economic growth from 1922 to 1929 in America (Harrison and Weber, 2009). In addition, his continuous endeavour to expand his scientific activities, his study in biology, and physical chemistry of the human body led to many research programs in medicine. As medicine was one of the fields that advanced the most during the Roaring Twenties, Gibbs potentially had contributed towards the development of medicine by inspiring future generations.

Gibbs surely had an indirect impact on the Roaring Twenties; however, it did not end there as he was being considered as one of the greatest modern scientists to this day. This is because his discoveries in thermodynamics and chemistry are being taught to students and used in different fields of science to this day. Also, his influence on other scientists is still being carried on today as some led to intelligent discoveries. For example, Albert Einstein was influenced by Gibbs' studies in statistical mechanics allowing him to continue his studies aiming to propose the second law of thermodynamics utilizing mechanics and probability while Gibbs focused on presenting a mathematical condition for statistical equilibrium (Inaba, 2015). His impact directly on academia as well as various practical applications is what kept Gibbs close to the world to this day.

10.4 Unnoticed but Timeless

Gibbs worked at a time when there was little ambition for serious theoretical science in the United States. His research was not easily understood by his students or his colleagues, and he made no effort to popularize his ideas by advertising for their exposure to the world. However, the work he had accomplished, whether it was easy to understand or not, was some of the most influential scientific research of all time. So many might wonder why a scientist of his importance is not known by the average person. Gibbs was a quiet, bookish figure, with no interest in self-promotion, who rarely socialized and never married but was still very content with the life he lived. He wrote in a complicated mathematician's style that tended to conceal the intellectual treasures his work contained. Gibbs deserves to be known, and his accomplishments recognized, as he was described by many as "one of the great creative scientific geniuses of all time." However, Josiah Willard Gibbs was a scientist that only other scientists would understand. He quietly did what he did; what he did was very important; and then, just as quietly as he changed the world of science and mathematics, he disappeared. Unless you're familiar with his field, you would never hear his name; and maybe that is what he intended. Gibbs was the scientist the world deserved but was not a scientist very well recognized for his work. So, he will continue to float under the radar. Because that is maybe what he wanted. He was the silent physicist, the diligent mathematician, the greatest scientific genius you might have never heard of.

11 List of Contributions

Amir A. Aliabadi received his bachelor's and master's degrees in Mechanical Engineering, in 2006 and 2008 respectively, from University of Toronto, Toronto, Canada, and his doctoral degree in Mechanical Engineering in 2013 from University of British Columbia, Vancouver, Canada. He is an assistant professor of engineering in the Environmental Engineering program at the University of Guelph, Canada. He is specialized in applications of thermo-fluids in buildings and the environment. Prior to this position he was a visiting research fellow at Air Quality Research Division, Environment and Climate Change Canada from 2013 to 2015 in Toronto, Canada, and a research associate in Department of Architecture at the Massachusetts Institute of Technology (MIT) from 2015 to 2016 in Cambridge, U.S.A.

Reza Aliabadi graduated from University of Tehran, Tehran, Iran, in 1999 with a master's in Architecture, and founded the "Reza Aliabadi Building Workshop". After completing a post-professional master's of Architecture at McGill University, Montreal, Canada, in 2006 and obtaining the OAA license in 2010, the workshop was reestablished in Toronto as atelier Reza Aliabadi "rzlbd". He has established a strong reputation in both national and international architectural communities. Local and global media have published many of rzlbd's projects. He has been invited to install in Toronto Harbourfront Centre, sit at peer assessment committee of Canada Council for the Art, speak at CBC Radio, give lectures at art and architecture schools and colleges, be a guest reviewer at design studios, and mentor a handful of talented interns in the Greater Toronto Area. He also had a teaching position at the School of Fine Arts at the University of Tehran and was a guest lecturer in the doctoral program at the same university. Artifice has recently published Reza's first monograph "rzlbd hopscotch". He maintains an ongoing interest in architectural research in areas such as microarchitecture, housing ideas for the future, and other dimensions of urbanism such as compactness and intensification. Beside his architectural practice, Reza also publishes a periodical zine called rzlbdPOST.

Hossam Elmaghraby Abdelaal received his bachelor's and master's degrees in Mechanical Engineering, in 2011 and 2014 respectively, from Cairo University, Egypt. He is currently working on his doctoral degree at the School of Engineering, University of Guelph, Canada. His current research focuses mainly on studying the dispersion and movement of infectious airborne particles in aircraft cabin environments using computational simulation tools. He investigates various means of controlling and mitigating the infections caused by these airborne particles. Hossam worked as a graduate teaching assistant for the course under supervision of Amir A. Aliabadi. He was tasked with revising the essays and providing comments to students.

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ISBN 978-1-7751916-1-2