THE WALK OF LIFE

VOL. 01

EDITED BY AMIR A. ALIABADI

The Walk of Life

Biographical Essays in Science and Engineering

Volume 1

Edited by Amir A. Aliabadi

Authored by Abhishek Vyas, Laura Alvarez, Matthew Grekula, Patricia McMullan, Anita J. Taylor, Matthew Bradley, Sandra Dusolt, Philip Labarge, Mishal Mansoor, Tom Rawlinson, Ryan Byerlay, Navneet Kullar, Sean Ratcliffe, Halla Salih, Stephanie Roth, Devon Huang, Ala Zeidan, Samanta Martinez, Amanda Pinto, Molly Corrigan, Galen Woods, Jason Wilson, Peter Soligo, Brady Ellsworth, Katharine McNair, Sarah Ormel, Cameron Fischer, Kurt Vendrig, Rachael Vanderlee, Kimberly Swain, Darian Vyriotes, Shelby Hawkins, Juanita Arevalo Camargo, Braden Dennis, Ali Alaawad, Cole Merrill, Nicole Chin, and William Land

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Atmospheric Innovations Research (AIR) Laboratory, Environmental Engineering, School of Engineering, RICH 2515, University of Guelph, Guelph, ON N1G 2W1, Canada

At a given moment there is only a fine layer between the trivial and the impossible. Mathematical discoveries are made in this layer.

—Andrey Nikolaevich Kolmogorov

Dedication

Homa Ansari

Series Foreword

Technical courses in science and engineering are notorious for being dry and difficult. More so, with the accumulation of knowledge over centuries, these courses have become more and more challenging to the point that many students can feel overwhelmed and eventually lose the joy of learning about science and engineering. I witnessed this fact after I started offering senior level engineering undergraduate courses while realizing that the material was actually graduate level content when I was completing my own graduate studies. Nowadays, the same burden may even be felt at graduate level courses.

To remedy this situation, I decided to introduce a new component in my technical courses. I have been asking students to turn in a biographical essay about a prominent scientist or engineer whose work we study in the course. The objective has been multifold. First students can develop their writing and communication skills particularly the art of expression and persuasion. This is much needed in science and engineering schools with too much focus on technical content only. Second, they can understand the content of the course with respect to the arrow of time, i.e. the historical development of knowledge. For instance it can be observed how certain curiosity-based inquires have persisted over decades, if not centuries, to lead to groundbreaking discoveries. Third, and most importantly, this exercise helps students understand science and engineering within the broader context of economy, society, and environment. Some prominent figures have experienced unique and inspiring childhood periods; many have lived during turbulent sociopolitical times such as World War II (WWII); a few have struggled in vicious scientific rivalries; and others have made significant contributions despite limited resources or disabilities.

The introduction of the biographical essays in my technical courses has been mainly experimental, but very successful in my humble opinion. I have been amazed to see that students put their hearts into this activity. They have retrieved incredible and *hard-to-come-by* literature to support their fact findings. They have also investigated the biographies from unique perspectives, which is not necessarily the point of view of an experienced and professional biographer. They have also demonstrated eloquence and joy in their writings.

I am optimistic that, with the help of students, I can continue to compile more essays on a multi-year period to unravel unique lives of a wide range of prominent figures in science and engineering. The series shall provide food for thought and inspire the eager students in science and engineering as well as the ordinary reader curious about the subject. I am indebted to all students who have contributed their resources and time toward this effort.

Finally, neither the students nor I are experts in biographical essays. Therefore, it is likely that the content may be inaccurate, unrepresentative, or that the viewpoints improper or offensive to some readers. In this case, I take full responsibility for any criticism for my deficiencies in cross examining the facts or in fully verifying the content. I want to protect the students from any vulnerability, particularly given the fact that I have encouraged them to write these essays, and I have published their work. Perhaps, the most evident criticism is this: *why should such biographical essays be published while there is an enormous body of carefully examined literature on the subject?* The answer is simple: *to encourage and inspire students in science and engineering programs and to provide an alternative viewpoint from the side of future scientists and engineers who just get exposed to the content.*

I even encourage careful readers to contact me and provide any comments, notes, or corrections toward the improvement of these series.

Amir A. Aliabadi

Foreword

Walking

Before reestablishing my practice in Toronto, I had to complete 5,600 hours of internship. During this rather frustrating period, I developed a habit of quitting my job once a year and push myself out of my comfort zone in an adventurous trip. On one of these solo expeditions, I committed myself not to stay in the same city for two consecutive nights and backpacked round the world in 49 days; hopping all around while crossing out a list of my favourite *to-be-visited* items or places, from Le Corbusier's open-hand-monument in Chandigarh, to the Giza in Cairo, and to the Michelangelo's David in Florence. This widened my understanding of extreme social and cultural diversities of people, our *lowest common multiple* and our *greatest common factor*; it also taught me to respect, adapt, and accommodate any given circumstances.

In New Delhi, I had the privilege to visit the Birla House (now Gandhi Smriti), where Bapu, the great father of India, was assassinated on 30 January 1948. In the garden, there are footprints marking Gandhi's *last walk*, and as everyone could walk on those footprints, I could not resist the temptation and tried it. With the first few steps, I was just trying to keep my balance to stay within the walk, but soon I started to feel something else: a pace that had the lightness of his spirit and the weight of a committed life journey. Walking on those footprints commands you to attend into every single step, to think about the very last and the very next steps, to take those steps with a decision and not by default. The experience dictates a very particular pace, a pace that is charged with restlessness, dedication, compassion, devotion, and obsession. It encourages you to appreciate, respect, and cherish the life, every moment of it as a gift not to be taken for granted. It motivates you to have a mission of your own; to turn your life into a meaningful and adventurous *expedition* instead of a *tour*, which is nothing but a collection of neglected moments.

Following those footprints made me appreciate that *walk* is a beneficial exercise. The concept of travelling through the life journey of such influential figures and the hardships of their *walk of life* and the many branchings of the path, is *mind making* far beyond *mind stimulating* or *inspiring*. In fact, names and fames are not to be *bestowed* but *earned*, and this is only achievable by the art of walking. "None of our revolutionary heroes is worth a thing until he has been on a good walk", wrote Bruce Chatwin in one of his books *Anatomy of Restlessness*. Indeed, a good walk is continuous; it has an agenda and above all an intention.

I borrowed the title for this very brief foreword from an old essay written by Henry David Thoreau who himself was an avid walker, literally and intellectually. For him, it was one's journey of life that leads to the character of the individual. Of course, it is very ambitious, and almost impossible, to capture such walks of life in short essays. I would like to think of this series not only as a compilation of knowledge or information on big names; but also a reminder, a trigger, or a wake up call for all of us, if you will. As Thoreau says in his essay: "The highest we can attain to is not knowledge, but sympathy with intelligence".

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Preface

The essays in this volume result from the Fall 2016 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 Osborne Reynolds, Ludwig Eduard Boltzmann, Isaac Newton, George Gabriel Stokes, Johannes Diderik van der Waals, William Thomson, Johann Carl Friedrich Gauss, and Andrey Nikolaevich Kolmogorov. Most figures in this list (except for Kolmogorov) are too well-known and written about so that there is a large body of literature about their biographies. This makes this volume convenient and at the same time strenuous to compose and edit. While there was a wealth of information for students to access, the task of focusing on unique aspects of each figure's life has been the most critical for the students, particularly given the fact that they only had a word limit of about 2000 for each essay. Nevertheless, 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 carefully examined the essays and provided necessary corrections to implement. I am also indebted to my brother, Reza Aliabadi, a life-long mentor and inspirer for my ideas and directions in life, who also wrote the foreword and 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

Contents

1 Osborne Reynolds (1842-1912)

A Brilliant Mind Ahead of His Time

By Abhishek Vyas, Laura Alvarez, Matthew Grekula, Patricia McMullan, and Anita J. Taylor

This paper aims to reflect on the life and legacy of Osborne Reynolds, taking into consideration the person and the engineer in the context of his life and the time of his work. With this, we want to highlight the brilliant mind behind such early discoveries and portray him as the innovator he was.

1.1 Early Life and Scientific Awakening

Osborne Reynolds was born in Belfast, Ireland on August 23, 1842. This prominent figure came from a family of Anglican clerics, but he diverged from this tradition by pursuing a career in science and engineering. His father was a very capable mathematician, a cleric and a scholar who gave young Osborne the education that allowed his mind to flourish. Reynolds had an irresistible interest in mechanics from a young age, which continued throughout the years (Launder and Jackson, 2011). At the age of 19, he became the apprentice of a well-known mechanical engineer named Edward Hayes. With Hayes, Reynolds learned the importance of a sound mathematical background in order to explain the concepts behind natural phenomena (Jackson and Launder, 2007). That understanding of basic laws governing the universe was what made Reynolds an innovator and what aspiring engineers need in order to develop ideas and technologies for the future.

After two years with Hayes, Reynolds started his studies in mathematics at the University of Cambridge, where his success gained notoriety. He graduated with honours in 1867 and immediately secured a fellowship at Queen's College. At the age of 25, Reynolds became the Chair of Civil and Mechanical Engineering at Owens College in Manchester which would later be known as the Victoria University of Manchester. Reynolds obtained this position with less than a year of experience but with the support of dozens of scholars at the time. At the beginning of his career at Owens College, Reynolds was a very enthusiastic man with a fresh perspective of the roles of engineers in society and a clear understanding of the fundamentals in his field. One of the challenges he found was the lack of laboratories at the university. He turned this problem into an opportunity to make the outdoors his laboratory, studying the physics behind nature for almost a decade. Overall, he was very resourceful and had an innovative way of thinking that defines how outstanding of engineers and scientists ought to develop. However, Reynolds thought he deserved to have his own laboratory and felt that Owens College was stopping him from developing his ideas due to its lack of resources. He applied for chair positions at other universities without success. Finally, Reynolds was provided with state-of-the-art labs in 1887 (Launder and Jackson, 2011).

Reynolds life was marked by tragedies such as the death of his mother during his childhood, the death of his first wife, Charlotte, due to childbirth of his son Osborne who also died in 1879. However, his work as a scholar fulfilled his life. During his years as a professor, he lived a regular life, worked on his research in the mornings, taught in the afternoons, and read newspapers before dinner. He enjoyed simple things in life such as going for walks with his friends during the weekends (Launder and Jackson, 2011).

Though other great scientists and engineers of his time such as George Gabriel Stokes and Thomas Edward Stanton who were students of Reynolds and Horace Lamb were knighted by the British government as a recognition for their scientific work, Reynolds never received that honour. Reynolds retired in 1905 due to his illness, what is now recognized as Alzheimer's disease and died on February 21, 1912 (Launder and Jackson, 2011). His work was fully appreciated many years after his death with his publications being ahead of his time.

Two of the many aspects that made Osborne Reynolds a historical figure are his prominent work in the study of turbulence turbulence and his contribution in naval design naval design and modelling of channels.

1.2 Fluid Mechanics and Turbulence

Reynolds is best known for his papers on fluid flow and turbulence, which were published between 1872 and 1894. Reynolds' brilliant mind made him a pioneer of ideas and theories that were instrumental for other theories developed 40 years later. The vast understanding humanity has on fluid mechanics can be traced back to one crucial point: the publication of *An experimental investigation of the circumstances which determine whether the motion of water shall be direct or sinuous, and of the law of resistance in parallel channels* by Osborne Reynolds in 1883 (Reynolds, 1883; Wu et al., 2015). Another of his most famous publications is *On the two manners of motion of water* published in 1884 (Reynolds, 1884; Gillespie, 1972). These two papers summarize his experimental work on streamline and turbulent motion of fluids and the conditions needed for these two motions to occur. The topics he addressed included wave motion, vortex motion, laminar and turbulent flow in pipes, dynamical theory of fluid flow, hydrodynamic lubrication and visualization of the internal motion of fluids (Jackson, 1995). One of the experiments Reynolds designed to prove his theory used a bell-mouthed glass tube, and by inserting a filament dye, he could observe the flow of the dye at different velocities (Gillespie, 1972). He concluded that for low flow velocities the filaments were straight. However, for high flow velocities the filaments were seen as broken and the coloured bands showed the existence of swirling regions of fluid (eddies), which filled the entire tube. In the Atmospheric Particulates course offered by the School of Engineering at the University of Guelph, students model the effects of turbulence in the particle collection efficiency of settling chambers, which is a practical application of what Reynolds studied and one of the many ways students are exposed to the theories Osborne Reynolds developed (Launder and Jackson, 2011).

Furthermore, the filament dye experiment helped Reynolds conclude that for multiple velocities, pipe diameters and viscosities the transition from one flow regime to the other occurred at a certain value of a dimensionless parameter that he established (Jackson, 1995). The results led Osborne Reynolds to define a constant to decide whether viscous or inertial forces dominate physics of fluid flow and the tendency of the water to create eddies. This dimensionless parameter was later named Reynolds number in his honour, which is used to differentiate laminar, transient and turbulent flows. Practical applications include the calculation of the friction factor in the Darcy-Weishbach equation , modelling of the movement of organisms swimming through water, wind tunnel testing to study aerodynamic properties of various objects, and wind lift on aircrafts. These applications would have never been developed if it was not for Reynolds work. Thus Reynolds' contribution still plays an irreplaceable role in modern physics and engineering more than a century after its conceptualization. With the use of his experiments, analogies and the discoveries, Reynolds has achieved a high place in the world of science and engineering. His practical work today is appreciated by scholars that dedicate their lives to educate new generations of engineers and scientists.

Although his discoveries in fluid mechanics are among his greatest accomplishments, there are also many important theories such as naval design that Reynolds studied throughout his life and demonstrate his impressive understanding of the laws that govern the physical world. Reynolds as the engineer he was, used physical representations to study wave motion which now has many applications today.

1.3 Naval Design and Wave Engineering

In 1876 engineering achievements that shaped the modern world started to emerge, including Alexander Graham Bell's first phone call and Thomas Edison's patent on the photocopier. Simultaneously, Osborne Reynolds was working on aspects of marine engineering and naval architecture that would later be recognized (Jackson, 1995).

Publications on racing of screw propellers in 1873 and 1874 showed Reynolds' increasing interest in ships (Jackson, 1995).

Reynolds' paper titled *Investigating Steering Qualities of Ships* was published in Transaction of the Institutions of Naval Architecture and tailored further analysis in ship safety (Jackson, 1995). In this paper, he argued that models in the form of steam-launching should be used for training naval officers in maneuvering of ships. At first, his ideas were overshadowed and ignored but once his theory became more popular and understood, the British Association appointed a committee with Reynolds as the secretary to lead the way for the development of advanced theories in relation to the maneuvering qualities of steamships (Jackson, 1995). The Committee of the British Association was conformed by some of the most distinguished scientists and engineers of the day.

Reynolds' work in this field was recognized during the time he worked in this committee when he received reports from ship masters who had successfully replicated experiments that Reynolds had previously done in the lab. The large scale application of his ideas of collision control and mastering of the steering mechanism in ships were demonstrated (Jackson, 1995). His contributions were of tremendous importance in the development of advanced technologies that lowered risks associated with loss of steering power under emergency situations in boats and ships.

In 1877, the wave analysis and the modelling of rivers and estuaries gained relevance and attracted Reynolds' curiosity. Reynolds then established a physical model to recreate and demonstrate the study of complex movements of water such as the River Mersey in the northwest of England (Reynolds, 1900). Reynolds recreated the tidal motion of the river to study the correlation between the wave speed in the model and that of the river. After conducting over 6,000 tide experiments, a mathematical correlation was calculated between the model and the real scenario. The evidence was so strong that the British Association acted to investigate waves and currents which lead to three detailed papers on this matter (Jackson, 1995). This theory lead to major advancements and opened up endless possibilities for modelling rivers and estuaries to determine the effects of proposed works in this field.

1.4 Final Remarks and Reflection

The true character of Osborne Reynolds can be appreciated through the quote: “To mechanical progress there is apparently no end: for as in the past so in the future, each step in any direction will remove limits and bring in past barriers which have till then blocked the way in other directions; and so what for the time may appear to be a visible or practical limit will turn out to be but a bend in the road.” (British Association for the advancement in science, 1887). This quote is a reminder to aspiring engineering students of the endless possibilities of accomplishing the difficult. Curiosity allows for the growth of passion and desire to develop new ideas. Additionally, it gives us the opportunity to make the world a better place with discoveries and inventions. Reynolds was inspiring due to his innovations in multiple fields, his capacity of adaptation to different situations and the use of his knowledge from the natural world. His characteristics were complemented by his dedication, ambition and desire to learn. These qualities make of him a role model for future engineers of this world to work hard, expand our mindset, and analyze what others have ignored. His achievements demonstrate there is still a lot to be done. Just as a great professor has said: “Engineering intuition is a powerful tool, but only to inspire further analysis, not to guide design”.

2 Ludwig Eduard Boltzmann (1844-1906)

Disorder in Life and Atoms

By Matthew Bradley, Sandra Dusolt, Philip Labarge, Mishal Mansoor, and Tom Rawlinson

We do not possess the ability to travel back in time. If an egg is dropped and subsequently breaks, it cannot be reassembled into its original form. But what if that was a possibility? Even though this seems impossible, it theoretically does not violate any law of mechanics. This creates a paradox in which something that we know to be impossible is actually very possible. We must then ask ourselves if then it is in fact impossible. The first person to question this was Viennese physicist Ludwig Boltzmann. He was a central figure in the development of *atomic theory* and is remembered for his two main contributions to physics. These are his interpretation of *entropy* as a well-defined measure of the overall disorder of a group of atoms, and the Boltzmann equation, which describes the statistical properties of molecules in a gas. The Boltzmann equation helps answer the question of how a broken egg can once again become whole. We have never seen an egg reform, not because it is *impossible*, but because it is very *improbable*. There are a massive number of scenarios in which the egg remains broken, but only one scenario in which the egg becomes whole again. Ludwig Boltzmann lived a life devoted to studying these scenarios and answering these questions. His life and contributions are merit for our attention and deserve our recognition.

2.1 Early Developments

Ludwig Eduard Boltzmann was born on February 20, 1844, in Vienna, Austria. He was born to Ludwig Georg, a tax officer, and Maria Pauernfeind, the daughter of a merchant from Salzburg. Ludwig Georg and Maria would also go on to have two more children, a boy named Albert, and a girl named Hedwig. Unfortunately, Albert would later die of pneumonia while attending secondary school (Cercignani, 1998). Shortly after the birth of Ludwig Eduard, Ludwig Georg was forced to move his family to Wels, and following which, they settled in Linz, Austria. It was in Linz where Ludwig Eduard began his education.

Boltzmann's early years were in a household with the means to provide him the opportunity to receive a solid education. Initially, his parents engaged a private tutor to instruct him. The first formal education Ludwig received was at a local gymnasium in Linz. While attending the gymnasium, Ludwig showed a strong aptitude and fervour for science and mathematics, and more often than not, he was proved to be the most proficient in his class. Of note, this stage of Ludwig Eduard's life was also marked with great hardship, when at the age of fifteen, his father died from tuberculosis (Cercignani, 1998). It is possible that the great hardship of the early loss of his father caused Boltzmann to throw himself into his studies, bringing to the forefront his interest and aptitude for the sciences.

2.2 Disorder in Atoms

At the age of 19, Ludwig Boltzmann enrolled at the University of Vienna as a student of Mathematics and Physics, graduating with a Ph.D. in a mere three years (Cercignani, 1998). In his short time as a student, Ludwig became friends with Professor Josef Stefan, who discovered the relationship between radiant heat and temperature. The very important scientific cooperation between these two figures led to the formulation and determination of the Stefan-Boltzmann constant (sigma), which is considered as a proportionality constant in Stefan-Boltzmann law stating that *the total intensity radiated over all wavelengths increases as the temperature increases*. Josef Stefan supervised and assisted Boltzmann while he began his work on the kinetic theory of gases. His work on the kinetic theory of gases is what led to his graduation in 1866 with his doctorate. In 1867, Boltzmann became an Assistant Professor and lecturer in Vienna. Boltzmann did not remain in Vienna for long, as in 1869 he was appointed as the Chair of Mathematical Physics at the University of Graz (Cercignani, 1998). It was here that, in 1872, Boltzmann published a paper that would contain the Boltzmann Equation.

Before Boltzmann's research, it was believed that certain things could not be witnessed because they were just impossible. However, after this discovery, it was known that this was only because of an event's extreme improbability. Shortly after this discovery, Boltzmann accepted a chair at the University of Vienna as a Professor of Physics, which was considered a high step in the academic community (Cercignani, 1998). On a personal note, Boltzmann was to meet his future wife, Henriette Von Aigentler, before leaving Graz to take up his new post.

Henriette Von Aigentler, was a teacher who lived on the south side of Graz. After her first meeting with Ludwig Boltzmann, she decided that she would study at the University of Graz as a student of Mathematics and Physics, perhaps influenced by Boltzmann. Problems soon arose among the faculty as they struggled with having to accept the first female student at the school. There was never an official rule banning women from attending the university, but a rule was soon put in place to deal with the issue. With Boltzmann's help, Henriette was able to appeal this rule and successfully became the first female student at a University in Austria. In 1876, Ludwig asked Henriette to marry him. The couple would go on to have two sons, Ludwig and Arthur, and three daughters, Henriette, Ida, and Elsa. In 1876, the Boltzmanns moved to Graz, as Ludwig was appointed to the chair of Experimental Physics. They would spend fourteen mostly happy years in Graz, and it is here where he would find one of his most important discoveries (Cercignani, 1998).

In 1877, Boltzmann published his paper *Probabilistic Foundations of Heat Theory*. This paper would hold the basis for the ability to measure entropy. He described a principle in which entropy is a mathematically defined measure of the overall disorder of atoms. This was the statistical definition of entropy, and it provided an explanation and understanding of the nature of entropy. Boltzmann described it as the degree to which the probability of a system is spread out over different possible states, or the number of ways in which a system could possibly be arranged. This led to the famous equation, using the Boltzmann constant, of $S = k_B \ln W$. This equation would become one of the most well-known accomplishments of Boltzmann career, and would be inscribed on his tombstone at the end of his life (Cercignani, 1998).

2.3 Disorder in Life

Near the end of Ludwig Boltzmann's time in Graz, events would transpire that would leave Ludwig in a troubling mental state. The first of these events occurred in 1885 when Ludwig's mother passed away. There is no record of Ludwig writing any scientific papers during this year, giving to speculation that he was significantly affected by the loss. The next event was his appointment as Rector at the University of Graz in 1887. This essentially put him in charge of the university, and specifically in charge of student discipline. This role, while a great honour for Ludwig, was proven to be a very tiresome endeavour, and would go on to increase the stress in Ludwig's life. It is around this time people observed that Boltzmann suffered from manic-depressive syndrome. In 1889, at the age of eleven, Boltzmann's son Ludwig would die. This event affected Boltzmann deeply, as he blamed himself for not realizing how serious his son's case of appendicitis had become. Two significant losses plus a stressful job contributed to Boltzmann's growing sense of isolation and insecurity, and pushed the Boltzmann family into leaving Graz (Cercignani, 1998).

In 1890, the Boltzmann family moved to the University of Munich where Ludwig was appointed to Chair of Theoretical Physics, which allowed him to teach a subject that he loved very much. He was able to take his knowledge of experimental physics and apply it to help illustrate theoretical models. His time in Munich would not last long, since in 1893, his friend, mentor, and Ph.D. advisor, Josef Stefan passed away. Boltzmann would then once again move to Vienna to succeed his friend as a Professor at the University of Vienna. Boltzmann did not remain in the position for long. He devoted a large amount of his intellectual effort defending his theories, and had trouble getting along with many of his colleagues in Vienna. These facts would push Ludwig to accept a position at the University of Leipzig in 1900, until he returned to Vienna two years later (Cercignani, 1998).

Boltzmann continued to teach physics throughout Vienna, and also lectured on natural philosophy. Boltzmann's lectures on philosophy were so successful that no lecture hall in Vienna could hold the number of people attending. It is in these years that Boltzmann's health began to deteriorate. His eyesight had deteriorated enough that he hired an assistant to read scientific papers to him and transcribe his work. Ludwig also began to experience bad attacks of asthma during the nights, which further interrupted his sleep. But it was his manic-depressive syndrome that would cause him the most problems. Ludwig would become exhausted and would fall into a state of depression after a visit to lecture in the United States. He felt as though his lectures were not as well received in the United States as he hoped they would be. After he returned from the United States, Ludwig, his wife Henriette, and their youngest daughter, travelled to Italy for a short vacation. On September 5, 1906, at the age of 62, Ludwig Boltzmann hung himself (Cercignani, 1998).

Ludwig Boltzmann completely devoted his life to science. He never worried about his physical and mental health, which may have eventually led to his death. It is believed that Ludwig Boltzmann suffered from manic-depressive syndrome which gave Ludwig two unique mood sets. When he was in the manic stage, he may have seemed very happy, waking up early in the morning, and working intensively throughout the day. Unfortunately, this stage would not last long, and a depressive stage would develop. The depressive phase brought a lack of sleep, unpleasant thoughts, and thoughts of suicide. It was in this depressive state that Ludwig likely influenced the final days of his life. His suicide is often believed to be in part because of the lack of recognition of his theories and research, however this is likely false. Ludwig was awarded numerous doctorates, medals, and was given extremely prestigious positions in the universities of Leipzig, Munich, and Vienna. Unfortunately, Boltzmann was a victim of the sacrifices of mind and body, made in the name of scientific discovery.

Physicists throughout the world mourned the loss of Ludwig Boltzmann. Many could not understand how such a great man could take his own life in this fashion. Boltzmann was a man who spent his life attempting to predict and prove how atoms and molecules behaved. With his interpretation of entropy, and the Boltzmann equation, which was used to describe statistical properties of a gas made of molecules, he became a central figure in the development of the atomic theory of matter. Before Boltzmann, the concept of an atom was seen as just a theoretical structure used to help support theories, while many prominent scientists did not share the same belief in atoms. Two years after the death of Ludwig Boltzmann, a physicist named Jean Baptiste Perrin would confirm the values of Avogadro's number, as well as Boltzmann's constant. This would finally convince the world that atoms did truly exist. This however was two years too late for Ludwig Boltzmann to see.

2.4 The True Meaning of a Sacrifice

Ludwig Boltzmann lived a very tragic life. He lost his father when he was just fifteen, and then watched as his mother and oldest son die when he was an adult. His later years were played by both his physical and mental health issues, which ultimately led to his early death. Many people, suffering from these issues would have struggled in any job or life situation, but Boltzmann thrived in his scientific endeavours. He gave his life to physics, and his discoveries in the field will make sure that his name is never forgotten.

3 Isaac Newton (1642-1726)

A Scientific Revolution

By Ryan Byerlay, Navneet Kullar, Sean Ratcliffe, and Halla Salih

Spacetime is the fabric in which we exist and is composed of two elements; *length* in three dimensions and *time*. Manifestation of energy as matter in this fabric is called *mass* and these three elements together unite to describe physical *force*; this is the most important and ubiquitous analog we possess to understand the world around us. This particular relationship comes from the multiplication of the mass and length units divided by the unit of time squared. The contributions of the man after which this unit was named are equally fundamental to our understanding of the world around us.

3.1 The Development of the Man

Sir Isaac Newton was an English mathematician and physicist born in a hamlet named Woolsthorpe-by-Colsterworth in the county of Lincolnshire (Bauer, 2007). It was Christmas day 1642, December 25 Julian Calendar, and his father after whom he was named had died just three months earlier. After this tragedy, his mother re-married and had three more children, Isaac grew disenchanted by his family situation, driving him to pursue purpose in other areas of his young world. The historical context for young Isaac was Europe two centuries into the Renaissance; the western world was discovering secrets lost to ancient civilizations and looking deeper into and out of the physical world. This gave Isaac's developing mind much to attend to and he spent his schooling years at the King's School, Grantham, pursuing early passions of the mind (Bauer, 2007). He would then be admitted to Trinity College, Cambridge, where excellence in the field of mathematics would see him excel to receive his BA and MA in succession, slowed down only by the Great Plague (Bauer, 2007). This was the period during which he developed his theories of calculus, the law of gravitation, and optics. He would go on to develop a long list of mathematical relations and procedures used to this day; these breakthroughs impressed his superiors, causing his ascension into the Royal Society of Londong. This gave him further access to resources which produced work such as a reflecting telescope, theory of the visible spectrum, empirical cooling law, studies in the speed of sound, classification of Newtonian fluid, and many other pursuits useful to the development of society (White, 1999). He is also infamous with igniting an altered-view of the blossoming scientific revolution with fringe pursuits such as alchemy and formulating predictions about the future fate of humanity.

His footprint on this world can be described as nothing short of a paradigm shift. He ushered in the classical era of physics and, through a well documented controversy, described the mathematics of change: *calculus*. At the time, what we know of today as *Science* was better known as *Natural Philosophy*. Analogous to the dogma of religion but instead used scriptures written by Greek Philosophers such as Aristotle as gospel. Newton was among the wake of figures during this time period to push past this form of reasoning to insist on deriving knowledge from the cycle of theory and experiment we know today as science. However, with this philosophical push came along a string of unconventional interests that have been the fascination of historians since his death in 1726, Julian Calendar. Among these fascinations were studies such as alchemy, the craft of purifying base materials into more useful materials through mystical and often poorly documented methods. A central aim of an alchemist of the time was to find or produce the philosopher's stone, capable of turning base metals into gold and extending life. As an alchemist Newton too sought the philosopher's stone, guided by the bible and his analytical mind. His studies of the bible and other fringe pursuit's provides us with insight into the motivations and insecurities that a man of this stature may have possessed.

3.2 Science, Religion, or Both?

Religion and Science both claim to pursue the same end; ultimate truths about our reality. In the midst of Renaissance the church in Europe accepted Aristotelian Science (Schwartz, 1992). This meant that the reasoning used by Aristotle to conclude that the motion of the planets was circular was used as an authority in the public sphere. The problem of planetary motion was at the centre of this sphere; the geocentric assumptions of Aristotle were beginning to be challenged. Astronomical pioneers such as Johannes Kepler and Galileo Galilei used it to begin a public shift away from this reasoning while Newton formalized the final piece of the puzzle. Kepler brought the then separate worlds of physics and astronomy together by publishing Heliocentric works while Galileo used his newly developed telescopes to observe the actual motion of the planetary bodies. Newton contributed to this movement by publishing his theories on what we now know as the Law of Gravitation using what some historians of science refer to as early proofs of differential calculus in his work *Philosophiae Naturalis Principia Mathematica* (Newton, 1687). Apart from being one the of most important publications in the history of science, the law of gravitation contained within these pages saw the end of the era of Geocentrism and eroded the credibility of the church in the sphere of physical truths. This began a life long theme of appealing against authority when necessary to answer questions by experiment and observation rather than philosophy alone. Newton helped establish this cycle of generating theory and interpreting experimental results in relation to the hypothesis as the basic structure of the scientific method that we cherish today (Jones, 2011).

Despite Isaac Newton's disposition to religious dogma with the world he was living in, he had to maintain a relationship with it. As religion and the pursuit of knowledge were so closely related during this historical time period, a standard practise for professors was to become an ordained priest of the Anglican Church. In 1669, Newton was to be recognized as a professor of mathematics however this disagreed with his view on Christianity. He believed that the Christian Church had departed from the teachings of Christ from an early age and put his faith instead in the future coming of the Lord's Church (Jones, 2011). This put him at ends with the powerful Christian churches of the time however he saw no personal conflict with the further pursuit of the truth of Christ's doctrine's. Due to this firm disposition, he was the first professor of Trinity College in Cambridge to not be anointed an Anglican priest. This would plant the seed at Cambridge for university professors to pursue their work more openly for the sake of the knowledge it would provide as opposed to a holy mission.

3.3 The Scientific Method or Not?

His pursuit of religious truths apart from the dogma of the church drove him to apply the developing scientific method in attempts to resolve the questions he had about the doctrines of Christ, among other prophetic ends. His interests in his young and middle life became the obsessions of his older age when he devoted much of his time pursuing the craft of alchemy and decoding biblical prophecy. These fringe interests have produced a somewhat romanticized and mystical view of Isaac Newton.

Apocalyptic predictions are a fascination of human culture, especially when made by a source largely deemed by the culture as credible. Newton did not break this rule and may be responsible for a portion of our modern culture's obsession with the subject. Differently than alchemy, he was not able to apply the scientific method as there is obviously no practical experiment to test the apocalypse. Instead, he used his analytical mind to formulate new methodological approaches to interpreting scripture. Among the philosophies of this approach lies a totem of scientific reasoning from first principles; attempt to simplify to the fundamental elements. By applying this method to the bible he attempted to find the most literal meanings of the writings in order to create a model of predication for the end of our world. Through his biblical studies, Newton reached the conclusion that doomsday was to occur in the year 2060 (Snobelen, 2013). However, this prediction is not the conventional end of the world prediction. Newton's doomsday consisted of a foreplay of plague and war at which point the second coming of Christ would save humanity and usher in a 1000-year reign of saints on earth. An interesting aspect of this prediction was that he included himself as one of the saint's reigning over the earth during this period. This reminds us that even the most intelligent people fear death to the point of obsession. It is also a theme that has become relevant in our modern times as the year of his prediction is yet to pass and as our modern culture continues to develop its fascination with the apocalypse, in practise or in theory.

Another insight into Isaac Newton's fascination with prolonging life is clear in his pursuit of Alchemy and the philosopher's stone. Betty Jo Teeter Dobbs published the foundational work Newton did with alchemy, it was released in 1975 and called *The Hunting of the Greene Lyon*. Dobbs revealed the magnitude of Newton's obsession showing that he lavishly indulged in alchemy from the same year he was sworn in at Trinity College and refused priesthood until his death in 1727. At the time of his death, almost 10% of his personal library of 1800 books consisted of works on alchemy, with a great deal of these being his own manuscripts and notes on the subject. He documented the use of his personal laboratory where he again applied the scientific method to this process to further his understanding. This laboratory contained hand-built furnaces where he would conduct his alchemist experiments at Trinity College in Cambridge. He would complete these works writing over one million words on the topic along with hoarding a vast and secretive collection of papers, books, and elaborate dictionaries for his own private consultation. This accumulation of knowledge has been a great source of enthusiasm for historians ever since Dobbs published the first glimpse of this pool of work in 1975.

Focal to Newton's work in alchemy was the pursuit of the philosopher's stone: a treasure of the mind during his time also known as the elixir of life, occult gold, manna, or dew. This mythical material is said to have supernatural powers such as turning lead into gold or indefinitely extending human life. The supernatural condition of this object is likely what drove the vigour of Newton's pursuit; if he could demonstrate an effect outside our natural understanding of the world he would be doing more to push the limits of our knowledge than another mathematical procedure could. History shows that he resolved to pursue both in parallel, however he kept his work in alchemy unpublished. He could have made this decision for several reasons but the fact is the demand for work in alchemy was low. Finally, in 1936 these works were recovered by the Royal Society of London and sold at auction for 9000 British pounds (Greshko, 2016). After this point, the notes were exchanged into private hands and the scholarly body wishing to examine them was not able to gain access. However, 2004 saw the birth of *The Chemistry of Isaac Newton Project* at the University of Indiana when some of this original work on alchemy was brought back into public access. This project seeks to examine the techniques and methods used by Newton in his personal Trinity College laboratory.

The Newton Project is approaching these old techniques and methods with contemporary laboratory equipment and techniques. This approach could yield insight into Newton's thought process during this historic period of time where he was making many other great discoveries in parallel. However, in terms of yield of knowledge of the physical world this process will likely fail to make any major impact on our current model of the universe. An important totem of science that must be respected is the peer-review process; if his work on alchemy and the philosophers stone went unpublished for hundreds of years despite the assumption that other intelligent eyes gave it time, it is entirely possible that Newton was chasing false signals. Experimental procedure can be infinitely refined in the pursuit of a constant goal but yet yield no relevant results, as long as there is sufficient funding. One of the legacies that Isaac Newton may have inadvertently initiated is that of the mad scientist.

3.4 What About the Future?

Futurism and predictions on the path of technology may have ignited during the age of enlightenment, however, this flame is as well kindled in the new age. Ray Kurzweil is a well known futurist currently working for Google informing their machine learning and language processing efforts. The algorithms developed in the neural networks initiated by this man were used many times in the process of producing this paper; with the ubiquity of Google's language recognition engine it is becoming impossible to escape the societal benefit Kurzweil has generated. He is also known for making a wide array of predications about the immediate trajectory of our technological development, most notable of which is his prediction of the technological singularity occurring in the year 2040. Newton and Kurzweil can be said to be comparable figures within their historical time frames, in terms of the role they play in developing technological context and predicting where it will go. It is interesting to then note the hypothetical proximity of Newton's doomsday (2060) and Kurzweil's technological singularity (2040). Could these men have predicted the same event given different labels? This is likely just speculation but it provides the motivation to look forward in time with wonder and amazement.

4 George Gabriel Stokes (1819-1903)

Greatness beyond the Scientific World

By Stephanie Roth, Devon Huang, Ala Zeidan, Samanta Martinez, and Amanda Pinto

The past three centuries have marked an era in time in which the nature of science has evolved significantly. Over this time, the world has been gifted with intelligent, creative and logical individuals. These mathematicians, scientists and engineers have played key roles in contributing to the physical and natural sciences and have helped explain complicated theories about the way the world works. Some of the familiar names include Charles Darwin, Thomas Edison, Albert Einstein, and Isaac Newton. Most people seem to recognize these scientists and the work they have done, in part because they are the focus of key theories taught in schools. Another individual who deserves to be on the same podium as these famous scientists is Sir George Gabriel Stokes. A clever mathematician and physicist, Stokes dedicated his life to the sciences and served the greater community. His work focused on the behaviour of viscous fluids, the Stokes theorem of vector analysis, optics, and physics (Gillispie, 2008). Stokes also served as Lucasian professor, secretary and president of the Royal Society of London; dedicating his time to teaching and administrative work. Along with being an esteemed scientist and a valuable member to the educational community, Stokes was a family oriented individual and was often described as a creative, intelligent, and genuine human being (Barr, 1962).

4.1 Early Days

Sir George Gabriel Stokes was born on August 13, 1819 in Skreen County Sligo, Ireland into an evangelical Protestant family. His father, Gabriel Stokes, was the Protestant minister of the parish of Skreen. His mother, Elizabeth Haughton, was a daughter of a minister of the church (Craik, 2005). With both parents deeply involved with the church, Stokes had a very religious upbringing. He was the youngest of six children: three brothers and two sisters. The childhood home atmosphere was very happy, filled with young active minds (Barr, 1962). As a minister, Gabriel clearly focused George on the importance of religion but also introduced him to wider education and the knowledge gained from expanding horizons. It is interesting to know that all three of his brothers went on to become priests and follow in their father's footsteps. Stokes, on the other hand, created his own path and was more intrigued by the sciences. He wanted to be different. Though he broke the mould of tradition, it was known that his childhood home was near the water and exposure to the sea gave rise to his interest in waves and fluid flow and shaped his work in the years to come (Gillispie, 2008).

The value of education was instilled in Stokes at an early age. His father, Gabriel, was involved with education even as a minister and he made sure his son was given the opportunity to rise as an accomplished individual. This focus on education was rare and almost unheard of at the time since economic problems and financial difficulties in taking care of a large family imposed a significant barrier in educating children. However, education was of the utmost value to Gabriel and he indirectly helped pave the path for his son's contributions to the scientific world (Wilson, 2004).

Stokes completed primary education through his father and a clerk in the parish. He then left Skreen in 1832 to attend the Reverend R.H. Wall's school in Dublin. He was only thirteen years old at this time and became quite an independent man at a very young age. During the three years he studied there, his father passed away. Since his father had played such a key role in his life up to this point, dealing with the loss was tough for Stokes and he had a hard time coping with reality. In 1835, at the age of sixteen, Stokes moved to England. His mother somehow managed the expenses and sent him to the University of Bristol. The sacrifices that both his parents made to enable Stokes to complete his education were immeasurable. Stokes had the opportunity to be a part of a supportive and loving family; values he cherished for the rest of his life.

During his time at Bristol, Stokes' personality changed. This might have been due to the loss of his father. He became a very calm and sombre individual compared to the tempestuous and sometimes violent child he had been known to be. From this point forward, he was known for his timidity and quick one-word responses even to complex questions that required a great deal of thought. Despite his reserved nature, Stokes won many prizes for mathematics and had excellent recommendations from his Bristol professor, Francis Newman. In 1837, he broke family tradition and attended Pembroke College at the University of Cambridge instead of pursuing religious studies at Trinity College. Stokes graduated as senior wrangler and was the first Smith's prize-man. With these credentials, Pembroke offered him a fellowship upon graduation (Craik, 2005). Professors and colleagues alike started to recognize the intellectual capacity and passion Stokes had for the sciences.

4.2 Another Era for Applied Mathematics

William Hopkins, an avid mathematician and friend of Stokes, advised him to undertake research into hydrodynamics. Stokes followed his advice and published papers on the steady motion of incompressible fluids. One of his main papers was entitled *On the steady motion of incompressible fluids* in 1842 (Stokes, 1880a). Even though Stokes was proud of this accomplishment, he ran into challenges and disappointing findings. He soon learned that Jean-Marie Constant Duhamel, another mathematician, had already obtained similar results to his studies. Undeterred, Stokes persevered through the challenge and learned that Duhamel had been working on the distribution of heat in solids instead. The difference in application gave Stokes cause to argue his position and publish his work as independent research (Gillispie, 2008). Stokes continued investigating fluids and deduced the equations of motion. One of these equations, the *Navier-Stokes equation*, was worked on in conjunction with Claude Navier. Both Stokes and Navier studied flow in incompressible fluids and used the equation to show how forces acting both upon and within a fluid determine fluid flow. In his 1845 paper, *On the theories of the internal friction of fluids in motion* (Stokes, 1880b), Stokes inserted a continuity agreement to justify the internal friction of fluids and made the derivation of the Navier-Stokes equation more credible. This was probably one of his greatest achievements of his scientific career.

Stokes is also famously known for his derived expression, known as the *Stokes Law*, which explains the fluid frictional force exerted on spherical objects that are immersed in fluids with very small Reynolds numbers. Once the terminal velocity, density and size of a spherical particle are known, Stokes Law can be used to calculate the viscosity of any fluid. In addition to studying the behaviour of fluids in motion, Stokes advanced hydrodynamics, the aberration of light, wave theory, optics and the motion of pendulums (Wilson, 2004). With all the research and contributions made to understanding viscous fluids, Stokes was appointed Lucasian Professor of Mathematics at the University of Cambridge in 1849. This was a great honour for Stokes since Sir Isaac Newton had previously held the same position. He lectured on hydrostatics and optics while he had this position. However, the position paid very poorly and Stokes accepted an additional position as a Professor of Physics at the Government School of Mines in London. It was crucial for Stokes to be able to support himself through his career and he made sure he was able to make ends meet. These were lessons he had learned from his dedicated and financially responsible parents.

Stokes was a committed learner and a hard working individual. People recognized these qualities in him and he was elected to the Royal Society of London in 1851. The following year Stokes was awarded the Rumford Medal for his paper on light and wavelength (Gillispie, 2008). During the same year of 1852, he explained the phenomenon of fluorescence as a product of light whose wavelength had changed as a result of the substance it had been refracted from. In addition, Stokes presented a different paper on the composition and resolution of streams of polarized light. In the three years as part of the Royal Society, Stokes had shown a great deal of influence within the scientific community. It followed then that, in 1854, Stokes was appointed Secretary of the Society (Barr, 1962).

At this point of his life, Stokes was immersed in research. His life became more intense as he juggled research, published papers, handled Society work and taught at the University. Most of the papers he wrote were on mathematical topics deeply related to his physical experiments (Barr, 1962). Interestingly, one of his main arguments was that mathematics, in which he devoted much of his time, would always be secondary to physical experimentation in terms of developing scientific knowledge. Stokes, being a mathematician, clearly valued experimentation and the ability it had to aid in scientific explanations (Barr, 1962). By the middle of the century, Stokes was a widely demanded lecturer and heavily involved in almost every topic that related mathematics and science. He was a major contributor to the fame of the Cambridge School of Mathematical Physics and worked closely with Lord Kelvin to make that happen.

4.3 A Rare Example of the Balanced Approach

Starting a new chapter in his life, Stokes became engaged to marry Mary Susanna Robinson, the daughter of an astronomer at Armagh Observatory in Ireland. However, he had concerns regarding the marriage and his relationship with his wife. He felt that he would be unable to love passionately due the demands of his scientific life. For example, one of his habits was to work early into the mornings on physics and mathematics problems and he questioned whether it would affect a happily married life (Barr, 1962). While being engaged, Stokes wrote many letters to Mary making sure she was content with the engagement and even gave her the freedom to end it if she had doubts about the future of their relationship. These actions indicated that Stokes was a calm, cautious, and methodical person with genuine concern for people, particularly the woman he was about to marry. Eventually, he married Mary on July 4, 1857 at St. Patrick's Cathedral in Armagh and they had five children (Wilson, 2004).

Although he may not have expressly stated it, Stokes had a clear desire to have a life beyond the intense intellectual pursuits. He was looking for change in his life and hoped being married to Mary could help relieve the loneliness of his duties. After the marriage, he turned away from mathematical research and focused more on teaching, experimental and administrative work. Stokes vacated his fellowship at Pembroke College after his marriage since fellows had to be unmarried at the time. However, he soon regained the position in 1869 when this rule changed (Barr, 1962). Even though family became more of a priority, Stokes was still greatly trusted and people often asked for his feedback on their research. He was able to continue as Secretary of the Royal Society of London and was elected President of the Society in 1885, the first man to hold all three Society positions since Newton. Stokes received the Copley Medal from the Royal Society in 1893 and was given the highest possible honour of serving as Master at Pembroke College (Barr, 1962).

His renown did not end there. Stokes was appointed President of the Victoria Institute in 1886 and held this position until death. The position explored the relationship between science and religion. He sided with Lord Kelvin and other scientists in the view of the Darwinian theory of evolution, though it opposed his religious roots (Wilson, 2004). In the decade before his death, he delivered lectures under the title Natural Theology and spent his final years living with his daughter, Isabella Lucy. Sir George Gabriel Stokes died on February 1, 1903 at his cottage in Cambridge and was buried in Mill Road Cemetery (Barr, 1962).

Sir George Gabriel Stokes was an outstanding intellectual individual who dedicated his life to understanding mathematics and applying those theories to the wonders of science, including the behaviour of fluids in motion, hydrodynamics, light, optics, and fluorescence. His religious background was always present but he was deeply intrigued by the unanswered questions that surrounded him. His contributions to the scientific world are embedded in the equations that bear his name, including the Navier-Stokes equation and the Stokes Law. Along with researching and publishing papers, Stokes made sure he devoted time to teaching and encouraging students in their pursuit of science. His positions at the Royal Society of London indicated the passion he had for the sciences and his genuine nature to help those involved in the scientific community. Along with being an intelligent mathematician, he was a passionate professor, caring husband, and a remarkable human being. Sir George Gabriel Stokes exemplified a balanced life, one with care and adoration for those he loved while making significant contributions to the scientific world.

5 Johannes Diderik van der Waals (1837-1923)

Beyond the Nobel Prize

By Molly Corrigan, Galen Woods, Jason Wilson, Peter Soligo, and Brady Ellsworth

Johannes Diderik van der Waals was a brilliant physicist who had several significant findings on the continuity of gas and liquid states. Born in Leiden, Holland, on November 23, 1837, van der Waals would pursue a career in education that would eventually lead to revolutionary work in the field of physics and molecular forces (Oesper, 1954). His thesis, *On the Continuity of Gaseous and Liquid States*, was a transformative piece of work still with a great deal of significance today, over hundred years later (van der Waals, 1988). His work expanded into topics of thermodynamics and fluid relationships. Van der Waals' work at Amsterdam University, along with a handful of other influential Dutch scientists of the time, inspired what some historians call the *Second Golden Age* of Dutch science (Tang and Toennies, 2010). His awards and recognitions, including the 1910 Nobel Prize in Physics, certainly attest to the fact that he is one of the most highly regarded scientists of all time.

5.1 A Humble Beginning

Van der Waals was the son of carpenter Jacobus van der Waals and Elisabeth van den Burg and was the eldest of their ten children. Beyond this, information about van der Waals' early childhood is quite limited. It is believed that the circumstances of coming from a humble family prevented him from pursuing education beyond elementary school, however at the young age of fourteen, he began teaching at a primary school. In 1861, van der Waals, driven to succeed further in his teaching career, wrote a series of examinations that allowed for him to be a director in primary schools (Valderrama, 2010). Four years later, this momentum continued when van der Waals was appointed to teach in the Hogere Burger School (HBS) system, a type of secondary school for middle class children.

The year 1865 was a monumental one for van der Waals' career and personal life, as it is also the year when he started a family of his own, marrying eighteen-year-old Anna Magdalena Smit (Tang and Toennies, 2010). In the years to come, the couple had three daughters followed by a son. Van der Waals continued his teaching career while continuing to support his growing family. Hardship struck the family in 1881, when van der Waals' wife passed away after falling ill with tuberculosis, at the young age of 34 (Tang and Toennies, 2010). The eldest in the family, Anne Madeleine, took on the role of supporting her family and running the household after her mother's tragic passing. All of his children were evidently very inspired by their father, as his daughters pursued careers in education, and his son followed suit with a career in physics. His son, Johannes Diderik Jr., would become a physics university professor and in 1908, he succeeded his father as the Physics Chair of the University of Amsterdam (Valderrama, 2010).

Van der Waals’ modest upbringing prevented him from attaining higher level education, which was taught in the classical Greek and Latin languages, during his time (Valderrama, 2010). This acted as a significant barrier in his career advancement as he was unable to enrol in traditional courses at university, because the entrance examinations required this level of education and language skill. Van der Waals’ remained driven to continue his education, despite this barrier and in the period of 1862-1865, he attended classes at Leiden University (Tang and Toennies, 2010). Through this he achieved certificates in mathematics and physics, which attributed to his appointment as an HBS teacher, as these new schools focused heavily on science and math (Valderrama, 2010). This educational reform of HBS schools and policy changes in the Netherlands during the 1860s, favoured van der Waals’ adverse situation as he was granted an exemption, enabling him to apply for universities (Valderrama, 2010). The improvements to the Dutch education system impacted the history of science and engineering for the years to come; it is what many historians attribute the bloom of successful Dutch scientists in this time (Tang and Toennies, 2010). Van der Waals, the chemist Jacobus Henricus van ’t Hoff, the physicists Hendrik Lorentz, Heike Kamerlingh Onnes, and many other notable scientists flourished during the transition to the HBS schools, and there was a boost in scientific research throughout the country. It was a huge advancement for the Netherlands and played a role in five Nobel Prizes in the sciences given to Dutch recipients between 1901 and 1913 (Tang and Toennies, 2010).

5.2 The Scientific Breakthroughs

No longer faced with the barrier of not receiving a traditional university education, van der Waals was able to sit for university exams and shortly after, he defended his doctoral thesis in June, 1873. This was a milestone in the study of molecular structure as it unveiled the *equation of state*, which proved that gas and liquid states of matter are of the same nature and will merge into one another in a continuous manner. The findings of his thesis were significant because at the time of his discovery, the molecular structure of liquids and fluids was seen strictly as a chemical phenomenon. Given van der Waals' aptitude for knowledge, he continued his research on the interaction of gas and liquid states of matter. His ingenuity led him to believe that different volumes of molecules would create different intermolecular forces between molecules. Therefore, by combining his equation of state model with experimental findings on the relationship between the pressure, volume, and temperature of gases and liquids, van der Waals was able to develop a relationship between the size of molecules and their attractive strength. Today, this attractive strength is known as the intermolecular forces between molecules or van der Waals forces (Tang and Toennies, 2010).

Soon after van der Waals received his doctorate, he was appointed director of the HBS school he worked at in 1874, then four years later Director of Secondary Education in Hague (Tang and Toennies, 2010). Despite understanding the significance of van der Waals' thesis today, at this time his influential work was not recognized by the academic world until after those four years had passed. The delay in academic recognition could possibly be attributed to the language barrier, it took time for van der Waals' thesis to be translated from Dutch to English, German, and French (Tang and Toennies, 2010). In 1878, van der Waal was appointed Head of the Physics Department at the newly established University of Amsterdam. This university is where van der Waals remained for the rest of his career, teaching and continuing to publish influential works in the fields of fluid relationships and thermodynamics.

Although Johannes' van der Waals forces was arguably his most significant finding, his other contributions must not be overlooked as they provided the foundation for several scientific findings. Another one of van der Waals' greatest discoveries was the *Law of Corresponding States*, which used his equation of state to relate the deviation of a substance from its ideal behaviour when subjected to a critical pressure, critical volume, and critical temperature. Van der Waals' Law of Corresponding States was significant because it provided the foundation for James Dewar's finding of the liquefaction of hydrogen in 1898 (James Dewar is best-known today for his invention of the vacuum container used in liquefaction of gases), and Heike Kamerlingh Onnes' finding of the liquefaction of helium in 1909, which led to his Nobel Prize in 1913 for low-temperature studies. Both Dewar and Onnes stated that van der Waals' findings provided the foundation for their research (Tang and Toennies, 2010).

Van der Waals was also very interested in the study of thermodynamics. Thus, two more of his findings were related to this field of study. The first of his findings was *Theory of Binary Solutions* (1890), which related his equation of state with the *Second Law of Thermodynamics* (as presented by Josiah Willard Gibbs). Van der Waals was able to develop mathematical formulas and create a graphical representation of a particle's free energy, known as *Gibbs free energy*. His second finding, the thermodynamic theory of capillary, came in 1893 where he put into question existing theories (presented by Pierre-Simon Laplace and Josiah Willard Gibbs) on how the density of molecules at the boundary layer between liquid and vapour changes. Van der Waals discovered that there is a gradual, however rapid, change in density at the interface between liquid and vapour. He also discovered that particles are in constant motion.

5.3 Beyond Recognition and Impact

Johannes Diderik van der Waals was awarded the 1910 Nobel Prize in Physics for his work on the *equation of state for gases and liquids*. Van der Waals also received several other prestigious distinctions such as an honorary doctorate from the University of Cambridge and was made an honorary member of the Imperial Society of Naturalists of Moscow, the Royal Irish Academy and the American Philosophical Society. He was also named a member of several other institutions such as the Royal Academy of Sciences of Berlin, Royal Academy of Sciences of Belgium, Chemical Society of London, the National Academy of Sciences of the U.S.A., and of the Academia dei Lincei of Rome.

Although van der Waals passed away in 1923, at the age of 85, the scientific discoveries he made will live on forever. Arguably his most profound contribution, the quantification of van der Waals forces has enabled physicists in the 21^{st} century to make sense of molecular interactions such as dipole-dipole attractions, dispersion forces, and coagulation or nucleation of atmospheric particulates. Understanding the physical applications of van der Waals forces, as well as his Theory of Binary Solutions, has provided the foundation for other major scientific contributions. Johannes' findings relating to thermodynamics are also still used today (Tang and Toennies, 2010). For example, the mathematical formulas and graphical relation van der Waals developed to depict a particle's free energy is used today by engineers to determine droplet formation of particles in the atmosphere. Physicists, engineers, and scientists throughout the world should have great admiration for what van der Waals was able to achieve with what little resources he had. Due to his passion and desire to understand how particles interact on an atomic level, the physical phenomena we see day to day can be understood and further explored.

6 William Thomson (1824-1907)

Reinventing the Essential

By Katharine McNair, Sarah Ormel, Cameron Fischer, Kurt Vendrig, and Rachael Vanderlee

Few scientists can boast of becoming knighted for their scientific achievements. Fewer still have been raised to the stature of noblesse for their work in thermodynamics and even fewer have had a major scientific unit named after them. William Thomson, later known as Lord Kelvin, can boast of all three achievements, among many others. The influence of his father and the incredible scientific achievements that took place during his childhood set the stage for his historic work later in life. Thomson's work touches on almost all branches of science, from thermodynamics, to geology, to acoustics. As his life went on, he steadily garnered the respect of scientists from all fields. Even once the bulk of his work was complete and he was advancing in age, his work commanded respect, and he was nominated for the Nobel Prize every year from his mid-seventies until he passed away (Flood et al., 2008). The impacts of his work are still seen today, and stretch beyond just the name of Kelvin as a unit of temperature.

6.1 The Power of Cultivation

When examining the life of William Thomson, one can see that his upbringing heavily influenced his life and accomplishments. William Thomson was born in Belfast in 1824 (Flood et al., 2008). Lord Kelvin's father, James Thomson, was born to a small farmer and thus was unlikely to have been able to enter university studies when he was young. Despite this, he became the Professor of Mathematics at the University of Glasgow, and authored several mathematical textbooks (Gray, 1973). This ambition and drive for education was passed down to his son, William, and therefore James Thomson had a large part to play in the scientist William became. His father's profession provided William with exposure to the scientific world at an early age, and so undoubtedly had an impact on his interests and education levels. At the age of ten, Thomson was enrolled in his father's university level Mathematics class, and both he and his young brother won several university prizes (Flood et al., 2008).

The scientific discoveries made in the time that he was growing up influenced his interests. Prominent scientists around the time include Joseph Fourier, Carl Friedrich Gauss, James Prescott Joule, Pierre-Simon Laplace, George Gabriel Stokes, and several others. On a family trip to Germany when he was sixteen, Thomson read Fourier's *Theorie Analytique de la Chaleur* in secret in an attempt to disprove Philip Kelland's criticisms of Fourier in his work *Theory of Heat* (Flood et al., 2008). This was not a common hobby for a sixteen-year-old boy, yet it shows how the scientific work at the time influenced him. As seen by Thomson's work on thermodynamics, his future career was heavily influenced by Fourier's work (Thompson, 1910).

6.2 Redefining Thermodynamics

By examining Thomson's life, one can observe the development of his ideas and interests in thermodynamics. His entry into the world of scientific papers began with a paper published in the Cambridge Mathematical Journal at the young age of sixteen. This paper was in defence of Fourier's aforementioned Theorie Analytique de la Chaleur. This first publication was followed by ten papers over his time at Cambridge, often under the pseudonym P. Q. R. (Flood et al., 2008). In 1847, Thomson attended a lecture by James Prescott Joule on some principles of thermodynamics. Joule provided a value for the amount of mechanical work required to raise a pound of water by one degrees Fahrenheit, and hypothesized a value for absolute zero at 480°F, or -248°C. Though this idea was held in disbelief at the time, it held a large amount of interest for Thomson. He even stated in a letter to his father, "he seems to have discovered some facts of extreme importance", (Flood et al., 2008). In retrospect, the correlation between these events and his later accomplishments are evident.

His later accomplishments were certainly significant, and duly recognized. At the young age of 22, Thomson was unanimously elected to the Chair of Natural Philosophy at Glasgow University. He maintained this position for 53 years. Twenty-six-year-old Thomson was elected a Fellow of the Royal Society of London, on the same day as Thomas Henry Huxley and George Gabriel Stokes (Flood et al., 2008). This provides perspective as to the other scientific work being performed at the time. In fact, Thomson has over fifty years of correspondence with Stokes. Thomson became heavily involved in the science and practical work of laying a transatlantic cable, and after many failures and many hours at sea, he was successful, and was awarded a knighthood by Queen Victoria for his work. His motto was "Honesty is the best policy" (Flood et al., 2008). The many hours spent on the ocean sparked an interest in navigation and telegraphy, and as such is likely responsible for his papers and patents in these fields. In 1852, Thomson married his second cousin, Margaret Crum, who passed away in 1870 after many years of sickness. Following his election to the President of the Royal Society of Edinburgh, Thomson re-married to Fanny Blandy in 1874.

In 1892, William Thomson was elevated to noblesse. His name, Lord Kelvin, was taken from the river Kelvin which ran near the University of Glasgow. This title was bestowed not only for his scientific achievement, but for his political actions regarding Liberal Unionism (Flood et al., 2008). His retirement from Glasgow at the age of 78 did not stop the flow of recognition. He was awarded the Order of Merit by King Edward VII, made a Privy Councillor, and elected Chancellor of Glasgow. William Thomson, also known as Lord Kelvin, passed away on December 17, 1907, and is buried in Westminster Abbey next to Sir Isaac Newton. A fitting resting place for this great man of science.

The impact of William Thomson on the scientific world can be evaluated by examining his scientific achievements in specific fields such as thermodynamics, geology, electricity, and navigation, in addition to his life and history. One of Thomson's successes includes his perfection of the theory of the ideal heat engine. This idea was initially put forth by a French Engineer named Nicolas Léonard Sadi Carnot. Thomson recognized that in order for the heat engine to be ideal, it would need to be reversible, and that the temperature difference between the source and the sink for heat – and the absolute values of these temperatures – would affect the amount of work done by the engine. From his investigation of the ideal heat engine, he invented his *absolute scale of thermometry* (Russell, 1912). The relationship of this new scale and a constructed practical scale was the next component to be determined. Along with Joule, Thomson conducted experiments to determine how gas followed the ideal conditions. These experiments involved "forcing the gas in a steady current through a porous plug and [observing] very accurately the temperature on the two sides of the plug" (Russell, 1912). It was from these experiments that Thomson, along with Joule, were able to determine that the temperature, on Thomson's scale, of melting ice was 273.7K. Correlating with these findings, the boiling point of water was found to be 373.7K (Russell, 1912).

6.3 Excellence beyond Thermodynamics

It was not only thermodynamics that brought Thomson recognition. Thomson's work in electricity ultimately lead to him receiving a Knighthood from Queen Victoria. In the mid 19^{th} century, the idea of an Atlantic cable began to be discussed among academics. Thomson began investigating the theory behind sending signals through a cable. Thomson's views about cables resulted in the manufacturing of high conductivity copper (Gray, 1973). This material was desired for the cable as the signals being sent through a wire were damped "proportional to the product of the resistance of the copper conductor and the total capacity of the cable" (Gray, 1973). The initial Atlantic Cable, designed by Wildman Whitehouse, was successfully operational for approximately one month after installation. On September 6, 1858, the cable was no longer receiving signals; Thompson, among other engineers, was responsible for conducting an investigation into the cause of this failure (Gray, 1973). After the failings of a second cable, the third was successfully installed in the year of 1866, with Thompson as the electrical engineer on both accounts. It was from this success that Thomson received a knighthood, as previously mentioned; he continued to assist with the laying of more cables, acting as an electrical engineer once again (Gray, 1973).

William Thomson was undoubtedly a brilliant and successful physicist, as proven by his work in thermodynamics, but one of his most remarkable accomplishments dealt with the branch of physical geology. In the mid 1850s, Thomson's broadening interest in the application of physical principles to the problem of geology led him to believe that the accepted concept of uniformitarianism put forth by geologist Charles Lyell was incorrect (Anderson and Lyell, 2007). He felt that this concept ignored the fundamental laws of physics, and in turn, led to a great deal of error in geologic theory. Determined to prove his theory, he spent the next forty years attacking the scientific basis on which uniformitarianism was built (Burchfield, 1990). With initially limited success, it was not until 1868 that geologists began to listen when Kelvin claimed that "a great reform in geological speculation seems now to have become necessary if geology were to be returned to the path of true science" (Burchfield, 1990). Yet this is exactly what happened. Following this geological reform, geologists began to develop a new approach to their studies; and, due to Kelvin's esteemed influence, the study of quantitative geology came about (Burchfield, 1990).

Kelvin, along with several other scientists, collectively discovered two major principles governing the principles of heat and energy (now known as the *first and second laws of thermodynamics*) (Burchfield, 1990). These theories proved the law of *energy conservation*, and that the universe was *running down*

(Burchfield, 1990). While continuing his study of heat and energy relations, Kelvin also undertook a closer study of the earth's layers, and began looking into the science of astronomy (Burchfield, 1990). Eventually, his studies led to multiple theories on the beginning of the earth, and the time at which it all began. All of Kelvin's research and hypotheses were significant contributors to the determination of the age of the earth. They provided a core foundation upon which all other subsequent theories pertaining to the earth's age were built. Perhaps most importantly, Kelvin's initial geological claim bridged the gap between different disciplines of science. He helped establish connections between geology, physics, mathematics, biology, astronomy, and many other areas of science that were formerly thought to be independent (Burchfield, 1990).

6.4 A Life in Perspective

A man with the intelligence, accomplishments, and titles of William Thomson cannot be summed up by only the discussion of his life or his accomplishments separately. Combining the examination of his life with the dissection of his achievements provides a more complete picture of the impact he had on the scientific community. Thomson's early life and the influences of scientists around this time set the stage for his future scientific work. He showed great promise and intellect from a young age, which was instilled in him by his father James. As his education continued, his intellect and scientific influence increased to the point where he was able to make significant contributions to the fields of thermodynamics, electricity, and geology, among other disciplines. His determination of a value for the lowest temperature possible (absolute zero) developed from his interest at an early age in thermodynamics (evident by his fascination with Fourier's work). Thomson's later work in electrical engineering while laying the transatlantic cable led to his interest in navigation, and started his ascent into nobility. His persistence with research in physical geology disproved the theory of uniformitarianism, which then led to the reform of standardized geological concepts. Following the acceptance of Thomson's new theories, supplementary work in geology and thermodynamics helped create a foundation for determining the age of the earth. The path his life took is intrinsically tied to his scientific work, and examining both provides a complete picture of who William Thomson, also known as Lord Kelvin, is. More than hundred years after his death, Thomson's discoveries are still being taught, and a huge proportion of current scientific research is based upon the principles that he devised. Due to his early exposure, his burgeoning passion, and his multidisciplinary approach to science and engineering, William Thomson became both a household name and a scientific legend.

7 Johann Carl Friedrich Gauss (1777-1855)

The Prince of Mathematics

By Kimberly Swain, Darian Vyriotes, Shelby Hawkins, Juanita Arevalo Camargo, and Braden Dennis

Unlike many legendary figures in mathematics and science, Johann Carl Friedrich Gauss lived an ordinary life. His life can be characterized by periods of success and loss. However, despite Gauss living an ordinary life, his contributions to mathematics and science were nothing short of extraordinary. To fully understand the genius that was Gauss, it is very important to begin his story in the early years of his life. The following paper will provide evidence regarding why Carl Friedrich Gauss earned the title of Prince among mathematicians based on his work in the 19^{th} century (Ratnana, 1997).

7.1 Childhood and Early Years

Carl Friedrich Gauss was born on April 30, 1777 to Gebhard Dietrich Gauss and Dorothea Benze in the German region of Brauncschweig-Wolfbuttel (Rice and Scott, 2005). Carl's mother was an intelligent but illiterate maid with no formal education, while his father worked as a bricklayer (Ratnana, 1997). Despite his parents having minimal education, Carl was able to teach himself how to read, write and perform elementary calculations before he was six years old (Rice and Scott, 2005).

In 1784, Carl was permitted to attend classes at his local elementary school. Carl's attendance at the school did not go unnoticed. Carl amazed his teachers with his knowledge of instantaneous summation of integers, which was something highly unusual for a student of his age (Ratnana, 1997). His teacher at the time, Mr. Büttner, was impressed and quite interested in young Carl's intellectual abilities (Bühler, 1981). Gauss' early mathematical talents resulted in feelings of anxiety for his father who wanted him to pursue bricklaying. However, with the help and encouragement of his mother, his father reluctantly allowed Gauss to enrol in Gymnasium (a school in Germany that prepares pupils for university entrance) (Ratnana, 1997). By the age of twelve, Carl continued to astonish teachers, where he was already attending gymnasium and criticizing Euclid's geometry (Rice and Scott, 2005). Without financial help from his parents, Gauss looked elsewhere for a financial sponsor to allow him to continue in his studies. As Carl's mathematics abilities continued to progress, he was able to attract the attention of the Duke of Brunswick, who later sent him to the Collegium Carolinum at age fifteen. During his attendance at the Collegium Carolinum, Gauss made his first important contributions to the field of mathematics. These contributions included his work on the prime number theorem and the construction of the regular seventeen-sided polygon with the use of only a compass and ruler. By constructing the regular seventeen-sided polygon, Gauss had successfully solved a two thousand-year-old Greek problem. With the success of this problem, Gauss made his first contribution to his mathematical diary dated March 30, 1796 (Ratnana, 1997).

After his schooling at the Collegium Carolinum, Gauss attended the well-known University of Göttingen from 1795 to 1798. At this point in Gauss' teenage years, he had begun discovering several significant theorems, where he focused his interests within number theory and algebra (Bühler, 1981). In 1799, Gauss obtained his doctorate in mathematics from the University of Helmstedt (Boyer, 1968). In his doctoral thesis, he proved the *fundamental theorem of algebra*, stating that every non-constant single-variable polynomial with complex coefficients will have at least one complex root (Rice and Scott, 2005).

7.2 Career

It is important to note that Gauss' interests in the manipulation of numbers were not confined to his early years. Throughout his career, he would go on to develop several theoretical concepts in many areas of science including the analysis of data and determination of astronomical orbits, the distribution of errors on random variation, geodesy, geomagnetism and potential theory (Bühler, 1981). Gauss' distribution of errors is also known as the *Gaussian distribution*. It consists of a symmetrical bell curve with the mean as the maximum point and the variance as the dispersion of the variable to the left and right of the mean. Gaussian Distribution has a very important role in the discipline of statistics. Computational programs use the distribution to generate a random variable with a mean parameter and standard deviation parameter. Gauss possessed an astonishing power of attention and concentration. Attributed to Gauss' strong-will, he continued to study uncontested concepts and produce concise and elegant arguments (Finkel, 1901).

After receiving his doctorate, Gauss successfully published a major contribution in number theory, the *Disquisitiones Arithmeticae*, in 1801. The Disquisitiones Arthmeticae is one of the greatest classics of mathematics literature consisting of seven sections including; the first complete proofs of the *law of quadratic reciprocity*, *fundamentals on congruence and residue class concepts*, and the *theory of binary quadratic forms* (Boyer, 1968). The topics discussed in Disquisitiones Arithmeticae focused on innovative mathematical concepts with a new depth of rigour, hinting that there was much to be done. The proofs included in the paper were lengthy and detailed drawing praise from Joseph-Louis Lagrange, one of the most influential mathematicians (Gray, 2015). The techniques produced in this literature were crucial bases for further research and remained influential up until the 20^{th} century (Ratnana, 1997).

Throughout his career, Gauss also remained fascinated in theoretical astronomy. Holding a post as the director of the astronomical observatory in Göttingen for many years, Gauss developed a theoretical basis in the determination of astronomical orbits in his time. During this time, many astronomers were attempting to predict the position of the newly discovered planetoid Ceres. In 1801, when the position of Ceres was formally discovered, it was almost exactly where Gauss had projected, in contrast to other astronomers. At the time, Gauss did not explain his calculation methods but it was revealed that this was one of the first applications of the least squares approximation. When Gauss was developing the least square estimates, he used the *Gaussian Elimination* approach. Gaussian Elimination is an algorithm of choice when solving a system of multiple linear equations and is perhaps one of the most well-known mathematics contributions by Gauss (Stewart, 1995). Based on his discovery of Ceres, he introduced his theory of motion of the celestial bodies in 1809. This theory predicted the behaviour of celestial bodies moving in conical sections around the sun and was later known as Gaussian gravitation constant in his later work. In recognition of his theories contributing to astronomy, he was honoured in 1810 with the Lalande Prize by the French Academy of Sciences (Dunnington et al., 2004). Gauss remained at the observatory, not seeking new positions, throughout the rest of his career.

In 1820, Gauss focused his studies to differential geometry of surfaces motivated by his work in the study of geodesy. By 1827, his theory was complete and quickly becoming a breakthrough in the field. His published theory introduced the Gaussian curvature of surface that focused on the improvement of Eulerian curvatures. The basis of the Gaussian curvature outlined that curvatures do not change as long as the deformation of the surface is without stretching or tearing, proven in Gauss' *Theorema Egregium*. The Theorema Egregium proved that the sum of the angles of a triangle differs from 180 degrees based on the proportional amount of curvature. Later, this proof led to the *Gauss-Bonnet theorem* that states the total curvature of a surface is topological invariant. When applying this theory practically, Gauss' work proved that constructing a constant scale map of the Earth is impossible (Ratnana, 1997).

By 1831, Gauss moved his focus towards physics (Ratnana, 1997). Wilhelm Eduard Weber joined him as a physics professor at the observatory in Göttingen. At that time, Gauss' and Weber's interests were focused on the study of terrestrial magnetism. Both professors worked towards understanding the source of the Earth's permanent magnetic field. Two years later, in 1833, Gauss and Weber had constructed an improved observatory with a customized declination apparatus, unifilar and bifilar magnetometers and the first practical electro-magnetic telegraph. This type of observatory and procedure became the universal adopted model for other astronomers around the world (Davy, 1955). Following this astronomical break-through, Gauss produced his first memoir on terrestrial magnetism focusing on the horizontal component of the Earth's field. The paper also included Gauss' method of proving experimentally the law of inverse squares and the introduction to absolute units in physics. Crediting Gauss with his contributions to terrestrial magnetism, the name Gauss was given to the units of magnetic intensity, only later being replaced to the unit of magnetic induction (Davy, 1955).

7.3 Personal Life

In 1805, Carl married Johanna Osthoff, a daughter of a local tannery owner in Brunswick. At this point in Gauss' life, he was still without a permanent job and heavily financially reliant on the Duke of Brunswick. However, when the Duke died from battle wounds in October 1806, Gauss was affected deeply (Ratnana, 1997). Gauss was left without financial assistance and had lost a life-long patron and friend (Rice and Scott, 2005). While grieving, he quickly found a professorship position of astronomy at the University of Göttingen shortly after in November 1806. In that year, his wife had a son Joseph and two years later, a daughter named Minna. In 1809, Gauss and his wife were once again expecting another child. However, during the delivery of his third child tragedy stuck. His wife passed away during the delivery and his third son Louis passed away a few months later (Ratnana, 1997).

In the following year of 1810, Gauss met and married his second wife Minna Waldeck who was one of first wife's close friends. Six years later in 1816, Gauss was a happy married man in a family of five, with three children from his second marriage (Eugene, Wilhelm and Theresa) and two from his first marriage (Ratnana, 1997).

During the period of 1817-1832, it was a particularly stressful time for Gauss. In 1817, he took in his sick mother, who remained with him till her death 22 years later. He also was having frequent arguments with Minna about moving to Berlin University, where Gauss was offered a job. Gauss however, did not like change and the family remained in Göttingen. In 1831, Gauss' second wife passed away after suffering from a long-term illness. As Gauss' genius for complex mathematical concepts was increasingly becoming known around Europe, Gauss became increasingly unpleasant and dismissive (Rice and Scott, 2005).

7.4 Legacy

Johann Carl Friedrich Gauss passed away in his sleep on February 23, 1855 (Rice and Scott, 2005). Following Gauss' death, his diary was discovered. Throughout the 78 years of his life, Gauss added incomplete ideas, concepts and proofs to this diary. However, Carl Friedrich Gauss was a perfectionist, he believed only after a theory was complete would it be sufficient to share with the world (Ratnana, 1997). Upon the discovery of this journal, it was found that he made several mathematical discoveries years before his contemporaries discovered them. It was said that if Gauss had released his concepts at the time of discovery, it would have advanced mathematics and science by 50 years at that time (Bell, 1986). Even today, his journal entries remain a basis of several investigations into mathematical theory. By the very fact that many of his contributions are still relevant today, it is a testament to how brilliant Gauss truly was (Ratnana, 1997).

Johann Carl Friedrich Gauss made significant contributions to science and mathematics. Over the course of 155 papers, he contributed to fields of algebra, astrology, analysis, statistics and computation, geophysics, mechanics, geodesy, electrostatics, differential geometry, number theory, optics, and matrix theory (Rice and Scott, 2005). It is quite obvious when looking through his achievements and academic contributions throughout his life, that Gauss is one of history's most influential mathematicians, a prince in his field.

8 Andrey Nikolaevich Kolmogorov (1903-1987)

The Master of Chaos

By Ali Alaawad, Cole Merrill, Nicole Chin, and William Land

8.1 The Becoming of the Man

Andrej Nikolaevich Kolmogorov of Tambov, a city about 250 kilometres southeast of Moscow, Russia, was a prominent Russian mathematician and statistician. He is often described as one of the three most distinguished mathematicians of the twentieth century and is most commonly known for his work towards understanding probability and the many random, stochastic processes behind it. Born on April 25, 1903, Kolmogorov lived to an astounding 84 years. He attended the Moscow State University, where he subsequently gained his doctorate and became a professor. Kolmogorov's work touched on more than just the average layman's life – his work applied to financial markets, chemistry, meteorology, and the military. Where random processes were applied, Kolmogorov explained them. The main principle of stochastic processes state that the past outcomes have no bearing on future outcomes; however, Kolmogorov's historical work has played a large part in our future (Shiryaev, 1989).

Kolmogorov's mother, Mariya Yakovlevna Kolmogorova, died during his birth due to complications. His father, Nikolai Matveevich Kataev, was an agronomist who was exiled from Russia as a result of his participation in the revolution against the Russian hierarchy (Shiryaev, 1989). Kataev returned to Russia after the 1917 revolution but was killed fighting in 1919 during WWI. Kolmogorov's mother and father were never married and subsequently, Kolmogorov was left orphaned; he was eventually raised by his aunt Vera Yakovlena, with whom he was very close. Kolmogorov spent the majority of his childhood in Tunoshna, where his maternal grandfather, Yakov Stepanovich Kolmogorov, lived. Kolmogorov adopted his maternal grandfather's family name rather than his father's. Andrej's aunt eventually adopted him in 1910 and they moved to Moscow where Kolmogorov became a train conductor prior to attending university. In 1942, he married Anna Dmitrievna Egorova.

In 1920, Kolmogorov enrolled at both the Moscow State University and the Mendeleev Chemical Engineering Institute. By the age of nineteen, in the year 1922, he was teaching mathematics and physics at the nearby Potylikhin Experimental School. When Kolmogorov began university he had not committed to a specific subject; he studied mathematics, metallurgy, and Russian history. However, he soon realized his passion for mathematics and focused heavily on the subject. During his undergraduate, Kolmogorov wrote eight scientific papers, most of which were about trigonometric series and all were published in 1925. Kolmogorov's publications on trigonometric series may have been influenced by one of his biggest mentors, Vyacheslaw Vassilievich Stepanov who lectured him on these topics during his undergraduate degree. In addition, in 1925, Kolmogorov wrote his first paper on the most important topic of his career, probability. Andrej believed that, "the theory of probability as a mathematical discipline can, and should, be developed from axioms in exactly the same way as geometry and algebra" (Barnett, 1999). Kolmogorov continued to publish significant articles focused on probability theory and stochastic processes; by 1931, Kolmogorov had eighteen publications.

8.2 Freedom of Orientation and Expression

During Kolmogorov's time at the Moscow State University, he became known globally for his contribution to trigonometric Fourier series, garnering him attention for his work under Nikolai Nikolaevich Luzin. Kolmogorov had a healthy relationship with Luzin, often giving Luzin credit for his achievements. It was at this time in 1929 that Andrej met Pavel Uryson, who was also being influenced by Luzin. Kolmogorov developed affection for Uryson; however, Uryson was in a homosexual relationship with Pavel Alexandrov. Uryson later died in 1924, due to a swimming accident, and it was in 1929 that Kolmogorov and Alexandrov became intimate partners (Graham and Kantor, 2009). The two men spent weeks together, travelling over 2000 kilometres by boat, down the Volga River in Europe. The two traveled from Yaroslavl, Russia, to Sevan Lake, Armenia. Over the course of the trip Alexsandrov wrote a book on topology and Kolmogorov wrote a paper on the Markov process with respect to continuous states and time. The work was the beginning of diffusion theory and was published in 1931. This was contrary to Luzin's hopes, as he wanted the pair to continue to study set theory because he was an expert in the subject.

Kolmogorov and Alexandrov shared a love for swimming. In fact, they were often chastised for swimming nude, at the time known as *desnudos*. Despite the account that the pair were involved in a rather public homosexual relationship in the 1930s era of Stalinist oppression, they stayed on the better side of the law. Kolmogorov believed that, "the second half of the 1930s went by peacefully in Komarovka (Graham and Kantor, 2009). However, a fascist government lead to the arrest of thousands of people for political crimes with many dying in the custody of the Soviet Union. Notably, a former teacher of Alexandrov was arrested for political crimes. The teacher subsequently starved in jail during a hunger strike, yet surprisingly Kolmolgorov and Alexandrov did not raise a petition against his detainment.

In 1929 Kolmogorov was appointed as a professor at the Moscow State University. During his time as a professor, Kolmogorov would take his students on walks in the wilderness surrounding Moscow. The walks would spur cerebral conversation on the topics of applied mathematics, painting, architecture, and literature.

In 1931, Alexandrov petitioned against his teacher Luzin, stating that Luzin took credit for his students' work, supported the enemy through publishing work outside the U.S.S.R., and conformed to Orthodoxy (Donskoy, 2008). Luzin was removed from his post at the U.S.S.R. Academy of Sciences, an event often referred to as the *Luzin Affair* (Graham and Kantor, 2009). Kolmogorov stood by Alexandrov throughout the entire trial. Speculation on their behaviour included the understanding that the Russian police likely knew about the pair's homosexual relationship. This influenced Kolmogorov and Alexandrov to formally speak out against other high profile scientists who did not support the former political climate of the U.S.S.R.

8.3 A New Science

In 1938, Kolmogorov became the head of a new Department of Probability and Statistics at the Moscow State University. Kolmogorov expanded his area of study to turbulence caused by jet engines and planetary motion. In 1941 he published two important papers on the subject of turbulence (Youschkevich, 1983). In the early 1950s, Kolmogorov became inspired by an American engineer, Claude Shannon, to pursue problems relating to information theory. He defined a mathematical notion of quantity of information with the help of Akiva Yaglom and Israil Gelfand. In 1953 and 1954, he wrote two papers based on the theory of dynamical systems. Preceding this time, with the assistance of his students, Kolmogorov tackled several projects in cybernetics. These projects provided the basic fundamentals for later development in computer science. Computer science was a rising science and researchers started establishing it as a distinct academic discipline during the 1950s and 1960s. The majority of the computer science related findings were done in the physical and mathematical domains during these times. Kolmogorov stated in his article *Automata and Life*, "I am not related to creating the basic ideas of modern cybernetics. Norbert Wiener and Claude Shannon are. But the popularizing of these ideas in our country [Soviet Union] fell to my share" (Vitanyi, 2007).

During that period, all research completed by Kolmogorov toward dynamic systems resulted in the development of a general theory of Hamiltonian systems under small perturbations. These systems are practically adaptable in any magnetic field including plasma physics (Vitanyi, 2007). This finding created additional discussions and significant contributions to the development of KAM-theory, which was named after Kolmogorov. In 1956 Andrej Kolmogorov submitted a report *The theory of Information Transmission*, which included the mathematical modelling of information theory, the report has subsequently been utilized by mathematicians and engineers. At that time, Andrej Kolmogorov, together with his students, worked on *theory of automata* and the *theory of algorithms*. The result was the creation of the Kolmogorov–Uspensky machine or KUM, which is similar to the Turing a machine – a computing machine that manipulates symbols on a strip of tape based on a predefined set of rules. The difference between the Turing machine and the KUM is that Kolmogorov's machine used tape that could change topology, or simply a graph (Vitanyi, 2007). As a result of his achievements and contributions, Kolmogorov became the Dean of the Faculty of Mechanics and Mathematics at the Moscow State University in 1954 and held the position until 1958.

In the early 1960s, Kolmogorov continued to focus on writing articles based on the theory of algorithms and automata theory. These articles were heavily influenced by masterpieces of Russian poetry. In the late 1960s, Kolmogorov began to work on the *theory of pedagogy*, which is the method and practice of teaching. Kolmogorov was a notable member of the U.S.S.R. Academy of Pedagogical Sciences, known for improving the mathematical syllabus in soviet schools and textbooks (Uspensky, 1992).

8.4 A Passionate Teacher

In addition to his scientific contributions, Kolmogorov is known as one of the greatest teachers to have taught at Moscow State University. Kolmogorov was an avid organizer of the mathematical schools and clubs, facilitating social and thought inducing evenings in Komarovka. Kolmogorov's seminars focused on the discussion of mathematics; however, he did not leave out the value of developing music, reading poetry and discussing current events. Kolmogorov truly believed in developing his students into well-rounded academics, which is evident by his words,"an individual tends to absorb the surrounding spirit and to radiate the acquired lifestyle and worldview to anyone around, not just to a select friend". In 1971, Kolmogorov became a member of an oceanographic expedition based on research developed by Dmitri Mendeleev. His findings were published in the Great Soviet Encyclopedia. Kolmogorov was truly one of the greatest thinkers of the 20^{th} century, he believed that, "at a given moment there is only a fine layer between the *trivial* and the *impossible*. Mathematical discoveries are made in this layer". As Kolmogorov aged he developed Parkinson's disease, which eventually led to blindness and his death in 1987, he was 84 years old. Andrej Kolmogorov was buried at the Novodevichy cemetery in Moscow (Vitanyi, 2007).

8.5 Well Deserved Recognitions

Kolmogorov received several awards from different countries and scientific communities throughout his life for his significant contributions and lifelong devotion to science. These prizes include: 1941 State Prize, 1965 Lenin Prize, 1962 Balzan International Prize, 1980 Wolf Prize, 1986 Lobachevsky Prize, 1987 Lobachevsky Prize, and he received the Order of Lenin six times. Kolmogorov was also granted membership to the following scientific communities: U.S.S.R. Academy of Sciences (1939), Romanian Academy of Germany (1956), Royal Statistical Society of London (1956), Leopoldina Academy of Germany (1959), American Academy of Arts and Sciences (1959), London Mathematical Society (1959), American Philosophical Society (1961), Indian Statistical Institute (1962), Royal Society of London (1964), U.S. National Academy of Sciences (1967), and the French Academy of Sciences (1968). In addition, Kolmogorov was granted honorary degrees from the University of Paris, University of Stockholm, and University of Warsaw.

8.6 Self Awareness

During the Second World War, Kolmogorov's family was evacuated from Moscow to Kazan. He lived alone in Komarovka, where he wrote a message to himself beginning with the words, "this diary is dedicated to my 80^{th} birthday, with the wish to save enough sense at least to understand my own writings done in the age of 40, take them with sympathy, as well as with rigour" (Shiryaev, 1989). Kolmogorov consciously considered his life from 1943 until the end of his days. His scientific career was a total of 67 years, with his work covering over 300 research papers and articles on different topics. He considered himself a mathematician; however, the majority of his inventions existed in cybernetics, physics, biology and literature. On October 20, 1987, Kolmogorov passed as a recognized scientist and great mathematician.

9 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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