THE WALK OF LIFE

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EDITED BY AMIR A. ALIABADI

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Biographical Essays in Science and Engineering

Volume 9

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Knowledge must be verified through repeated observation.

—Al-Biruni

Dedication

Ms. Rahbar

Preface

The essays in this volume result from the Fall 2025 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 Al-Biruni, Yoichiro Nambu, Lise Meitner, George Boole, and Subrahmanyan Chandrasekhar. Students have accessed valuable literature to write about these figures. I was pleased with their selections while compiling the essays, and I hope the readers will feel the same too.

Amir A. Aliabadi

Acknowledgements

I am indebted to my brother, Reza Aliabadi, a life-long mentor and inspirer for my ideas and directions in life, who also designed and executed the cover page for this volume. I thank Peter Sharpe for carefully reading and evaluating the essays. At last, I am thankful to each individual student author, without whom this project would not have been possible.

Amir A. Aliabadi

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By Jacqueline Zenobio, Bushra Shahid, Jessica Bell, and Lillian Collis

1.1 Introduction

Over a thousand years ago, the Iranian polymath and scholar Al-Biruni made history from the top of a mountain when he calculated the radius of the Earth using only basic geometric and trigonometric reasoning based on direct observation. Remarkably, the value he obtained was astonishingly close to modern measurements derived from satellites. Today, Al-Biruni is regarded as one of the greatest scholars of the Islamic Golden Age and one of the most original polymaths of his era. His major contributions to mathematics, astronomy, geography, and scientific instrumentation continue to influence modern scientific methods. In atmospheric science and engineering, the same ideas that helped Al-Biruni view the Earth as a measurable system, such as gravity and drag, are key to explaining how particles move through the air. His work shows that by combining observation with math, natural processes can be measured and understood.

Al-Biruni approached science as a process of verification and comparison, which is a methodology that remains central across scientific and engineering disciplines today. His scholarship bridged ideas across cultures, disciplines, and environments, showing that deep understanding requires both technical skill and intellectual curiosity (Ahmad, 2010). This essay will discuss how Al-Biruni's early curiosity grew into a scientific method, how his technical work improved mathematical and engineering tools, and how his focus on evidence shaped his ideas about knowledge. Further, his combination of math, engineering, and curiosity helped shape modern science and shows how research can be done with accuracy, creativity, and openness to different ways of thinking.

1.2 Early Life and Education

Al-Biruni was born in 973 CE in Khwarazm (present-day Uzbekistan) near the Oxus River (now known as the lower Amu Darya). This region, situated at the edge of Central Asia, was a meeting ground where people from diverse backgrounds converged and exchanged ideas. The culture and politics of the area were shaped by trade and interaction between different civilizations. The resulting combination of Persian, Greek, and Arab traditions produced a unique intellectual atmosphere that shaped Al-Biruni's mind from an early age. In the book *al-Biruni: His Times, Life and Works*, Hakim Mohammad Said describes Al-Biruni as "an alert observer who was all the time ready to broaden his horizon of learning and a student of comparative studies par excellence" (Said and Khan, 1981), emphasizing that his genius arose from this environment.

From a young age, Al-Biruni was taught Arabic and Persian languages, Islamic studies, and the natural sciences. However, his greatest fascination lay in mathematics and astronomy. He liked that these disciplines demanded both precision and imagination. The diverse cultures and intellectual climate of Khwarazm, where ancient Iranian astronomy intersected with Indian numerical methods and Greek geometry, played a significant role in his early life. It is one of the key factors that nurtured his curiosity and methodical observational habits. His intelligence was evident early on. By the time he was seventeen, he had measured the latitude of Kath (the capital of Khwarazm) by observing how high the sun rose in the sky. He also tracked the sun's movement to determine when each season began. These early experiments demonstrated his strong mathematical ability, as well as his early belief that nature could be carefully studied, measured, and understood through observation.

Al-Biruni's first teacher was Abu Nasr Mansur ibn Ali. Abu Nasr Mansur ibn Ali was a member of the Khwarazmian royal family and a distinguished mathematician who introduced Al-Biruni to Euclid's geometry, Ptolemaic astronomy, and Indian astronomical theories. Additionally, Al-Biruni's foster father supplemented this training with lessons in botany and natural observation and encouraged him to collect plants, seeds, and fruits. These were early exercises that fostered a well-rounded mind in empirical study that would inform his later scientific method.

After the fall of the Khwarazmian dynasty, Al-Biruni travelled east with Sultan Mahmud of Ghazni (from Ghaznavid Empire), joining his expeditions to India. He lived there for thirteen years, during which he produced one of his greatest works, *Tahqiq Ma Li Al Hind* (or *An Inquiry into India*). His method in that text was grounded in careful observation, comparison, and rational analysis. Al-Biruni believed in the power of reason and observation to uncover truth, consistently aiming to test and compare the findings of earlier scholars rather than simply accepting them.

Ultimately, the same curiosity about the sky and the world around him that he had as a child in Khwarazm continued to guide his work throughout his life. His curious and careful nature, shaped in a world that valued learning from others, helped him bring together ideas from many cultures and develop methods of study that preceded modern science.

1.3 Scientific and Engineering Contributions

Al-Biruni's scientific achievements reflect a remarkable blend of mathematics, astronomy, and geography, grounded in both precision and inquiry. One of his most notable accomplishments was his geometric method for measuring the Earth's radius at Fort Nandana in present day Pakistan. He determined the mountain's height through triangulation and measured the dip angle from its peak to the horizon, using trigonometric calculations to treat the Earth as a sphere. His estimate was only about 0.3 percent off from the modern value (Muhsin, 2018). This experiment demonstrated both mathematical ingenuity and a commitment to evidence-based observation. Al-Biruni also advanced trigonometry into a systematic discipline. His *Qanun al-Mas'udi* and *Kitab al-Tafhim* integrated sine, cosine, tangent, and cotangent functions to solve spherical geometry problems, enabling accurate calculation of celestial coordinates, latitudes, and longitudes (Ahmad, 2010). By building extensive trigonometric tables and linking geometry to planetary motion, he turned trigonometry into a practical scientific tool, anticipating frameworks later used in Renaissance astronomy.

His understanding of geometry and mechanics also led to early contributions in engineering. Al-Biruni designed and refined scientific instruments, including the astrolabe, water clock, and other measuring devices, to enhance the accuracy of astronomical and geographical data. He applied mechanical principles, such as balance, leverage, and hydrostatics, to study density, pressure, and motion, demonstrating a clear understanding of how physical laws could be applied to practical technology. These innovations merged theory with function, laying the foundation for later developments in experimental mechanics and design. In *Qanun al-Mas'udi*, Al-Biruni also discussed the Earth's rotation, axial tilt, and celestial motion, proposing a dynamic cosmic balance that foreshadowed later gravitational theory (Ahn and Juraev, 2024).

Al-Biruni's geographical insights were equally innovative. His work extended beyond mapping to include climate, mineralogy, and environmental observation. In *Kitab al-Jamahir fi Ma'rifat al-Jawahir*, he analyzed the properties and densities of metals, gems, and minerals, combining measurement with early geochemical reasoning (Ahmad, 2010). He also noted how air density, dust, and humidity could distort perception, recognizing environmental effects that modern science attributes to atmospheric refraction (Ahn and Juraev, 2024). Across Central and South Asia, he recorded latitudes and longitudes, creating one of the earliest coordinate-based mapping systems. His observations of solar altitude refined knowledge of the Earth's curvature and axial tilt, while his recognition of polar day-night cycles reflected an advanced awareness of planetary motion. Drawing from geometry, trigonometry, and environmental study, Al-Biruni exemplified an interdisciplinary thinker. His belief that "knowledge must be verified through repeated observation" embodied an early scientific method shaped by Greek, Indian, and Persian influences.

1.4 Sociopolitical, Philosophical, and Ethical Perspectives

The political and cultural environment of the Islamic Golden Age had a profound influence on Al-Biruni's pursuit of knowledge. It expanded his access to a wide network of scholars and promoted collaboration across various geographic regions. The open exchange of ideas during this period was supported by royals, rulers, and scholarly institutions, which encouraged Al-Biruni to study texts in Greek, Sanskrit, and Arabic. This affirmed his belief that knowledge and discovery should serve the benefit of all people and furthered his curiosity and drive to deepen his understanding of the world. His exposure to diverse knowledge systems not only broadened his learning but also refined his methods of inquiry. Through self-directed education, he developed a comprehensive and balanced approach to science, one that integrated observation, mathematics, and philosophy. The freedom to correspond with scholars from different regions and countries, such as Persia, India, and Central Asia exposed him to new and unique worldviews. Being able to exchange ideas with scholars from places like Persia, India, and Central Asia exposed him to many ways of thinking. This broadened his understanding of how learning and discovery are universal. This not only expanded his knowledge but also strengthened his belief that the pursuit of truth goes beyond cultural and political divisions, which formed the basis for his lifelong commitment to fairness and ethics in study and research.

From a philosophical perspective, Al-Biruni was deeply committed to observation, honesty, and intellectual curiosity. He believed that knowledge should be based on evidence rather than assumptions and that truth must be sought with both humility and integrity. His writings reflect awareness of the moral and ethical responsibilities that accompany scientific research. These principles guided his work and hold true today in the importance placed on integrity, transparency, and accountability within modern research and especially within engineering. His ability to merge scientific reasoning with moral consideration demonstrates that Al-Biruni's philosophy was not only theoretical but also deeply practical.

Al-Biruni's dedication to ethical practice was evident throughout his career. He not only analyzed existing knowledge with high precision but also expanded it through experimentation and collaboration. His dedication to evidence-based inquiry is reflected in the laboratories he established across regions, with just a few being in Khawarism, Ghazna, Kabul, and Nandana (present-day Pakistan) (Ahmad, 2010). Through these efforts, Al-Biruni embodied what it means to be a true scholar. Al-Biruni pursued truth not for recognition or power, but for the advancement of humanity and the growth of collective understanding, which demonstrates his commitment to ethical principles and values.

1.5 Conclusion

The life and work of Al-Biruni is an example of how curiosity, mathematics, and engineering can come together to advance not only scientific knowledge but our broader understanding of the natural world. From his early education in Khwarazm to his remarkably accurate calculation of the Earth's radius, he consistently relied on observation, measurement, and comparison to investigate the phenomena around him. His developments in trigonometry, astronomy, and scientific instrumentation show how theoretical models become more meaningful when paired with practical experimentation and careful verification. Overall, Al-Biruni's accomplishments reveal how his scientific approach anticipated many of the principles that continue to shape scientific practice today.

Beyond his technical contributions, Al-Biruni's respect for diverse knowledge systems and his commitment to ethical inquiry demonstrate that scientific progress also requires an open mindset. Ultimately, Al-Biruni was far ahead of his time and many of his experimental methods, such as his hydrostatic balance for determining specific gravity, resemble the foundations of later scientific instrumentation (Sparavigna, 2013). Al-Biruni illustrates that even the most complex aspects of our world can be understood through science when approached with humility, dedication, and an open mind.

2 Yoichiro Nambu (1921-2015)

The Silent Architect of Modern Physics

By Keerthan Ragu, Saad Munir, Christopher Romeo, Darryl Blair, and Nathan Paré

Yoichiro Nambu was a Japanese American theoretical physicist whose research completely changed the outlook of the scientists regarding the matter's fundamental structure. He was not an engineer; however, the theories he invented are largely applied in almost all modern scientific and engineering fields, particularly nuclear systems, quantum materials, and advanced particle research. The concept of spontaneous symmetry breaking is mainly credited to Nambu, which later became one of the essential ideas in the Standard Model of particle physics. It not only provides a reason for particles to be massive but also accounts for the different appearances of forces across the universe while they are underlined by the same principles. Nambu's work was done after World War II (WWII) during the stimulation of both theoretical and experimental physics that was characterized by nations pouring money into high-energy research and scientific infrastructure (O'Raifeartaigh, 1997). His contributions were significant in bringing the highly complex mathematics down to the level of measurable physical behavior, thereby, throughout the development of both science and technologies the influence was felt in both ends. This essay will present the argument that Nambu's genius created a new paradigm in physics which was then effectively utilized in quantum science and engineering. The essay will shed light on his academic background, milestones, struggles with recognition and acceptance, and the continuity of influence of science and technology.

2.1 Early Years and the War

Yoichiro Nambu was born in Tokyo, Japan on January 18, 1921. His childhood years passed during a time of swift modernization, during which dramatic changes took place in society and culture. In the aftermath of the Great Kanto Earthquake in 1923, his family migrated from Tokyo to Fukui, where the controlled and heavy militaristic environment of Japanese schools during the 1930s instilled in him discipline, intellectual toughens, and persistence. An early curiosity in Nambu about mechanical systems and radio circuits led him to put together his own electronics from scratch foreshadowing his obsession in life to unravel the invisible forces behind physical phenomena (Nambu, 2009). Later in 1940, at the age of 19, Nambu enrolled in physics due to its mixture of both abstraction and natural law, at the Imperial University of Tokyo, without necessarily focusing on a specific specialization. Although theoretical particle physics received less attention during this period in Japan, the country's reception toward Nobel Prize winner Hideki Yukawa in the 1930s greatly inspired Nambu.

Amid World War II (WWII), Nambu's education was halted when he was drafted to the Imperial Army and was assigned to radar research. Even though this obstacle, put a pause on his theoretical work, it still provided Nambu with an insight into electromagnetic theory and mathematics of signal analysis. After serving in the war, Japan's scientific institutions were in disorder, however Nambu continued his research at the University of Tokyo where postwar conditions pushed his intellectual freedom further. Following this, he joined Osaka City University as an associate professor in 1949, earning his doctorate from the University of Tokyo in 1952. During these key periods, Nambu was strongly influenced by the seminars created by Shinchiro Tomonaga,. which influenced his imaginative approach to physics.

2.2 Theories

Yoichiro Nambu's contributions to theoretical physics reshaped the understanding of symmetry, mass generation and the substructure of matter. His principal tool was Quantum Field Theory (QFT), through which he constructed mathematical Lagrangians describing how particles and forces behave under symmetry transformations. Because his work was theoretical, Nambu did not conduct any laboratory experiments himself; instead, his methods were mathematical and computational, relying on analysis of field equations and symmetric properties. His most notable achievement was the introduction of Spontaneous Symmetry Breaking (SSB) into particle physics. Using the Bardeen-Cooper-Schrieffer (BCS) theory of superconductivity, Nambu proposed that the vacuum state of a quantum field could spontaneously break a continuous symmetry, even when the governing Lagrangian remained invariant. This connection revealed that the massless propagations, later termed Nambu-Goldstone bosons, arise when a system's ground state does not share the symmetry of its equations. This concept became the cornerstone of the Higgs mechanism and the Standard Model of particle physics. The Higgs mechanism explains how elementary particles acquire mass by interacting with a universal field called the Higgs field.

Building on this framework, Nambu and Giovanni Jona-Lasinio developed the Nambu-Joa Lasinio (NJL) model in 1961, demonstrating how fermions could acquire mass dynamically through symmetry breaking. The NJL model was expressed through a four-fermion interaction Lagrangian

$$\mathcal{L}_{\text{NJL}} = \bar{\psi}(i\gamma^{\mu}\partial_{\mu} - m_0)\psi + G\left[(\bar{\psi}\psi)^2 + (\bar{\psi}i\gamma_5\vec{\tau}\psi)^2\right], \quad (2.1)$$

where ψ is quark field and m_0 is current quark mass. This equation introduced a self consistent mechanism for mass generation without explicit symmetry violation, paralleling the behaviour of Cooper pairs in superconductors and predicting composite particles analogous to mesons. Later in 1969, he extended this innovation to string theory, proposing that elementary particles could be modeled as one dimensional strings rather than point like entities. This idea was formalized through the Nambu-Goto string action

$$S_{\text{NG}} = -T\int d^2\sigma\,\sqrt{-\det\left(\partial_a X^{\mu}\partial_b X_{\mu}\right)}, \quad (2.2)$$

Where T represents string tension and $\partial_a X^{\mu}\partial_b X_{\mu}$ represents the induced world sheet metric. This formulation provided the mathematical foundation for modern super-string theory and the ongoing quest for a quantum theory of gravity.

Nambu's models had profound scientific and technological impacts. The NJL model paved the way for the Higgs mechanism and ultimately the standard model of particle physics. It introduced methods later used in Quantum Chromo Dynamics (QCD), which describe chiral symmetry breaking and meson formation. These are key concepts in today's particle accelerator research at institutions such as European Organization for Nuclear Research (CERN). The Nambu-Goto string action provided the mathematical foundation of string theory and introduced geometric methods that later became essential in data modelling, quantum filed simulations and theoretical materials science. Nambu's ideas contributed to technologies based on quantum symmetry such as semiconductors and superconducting materials and high energy accelerator systems.

2.3 Challenges

Throughout his career, Yoichiro Nambu faced great scientific, personal, and ethical challenges, which eventually shaped his professional identity. His earliest challenges came in post-war Japan, where he had to work under conditions of extreme scarcity. Returning to a devastated Tokyo University, Nambu lived for years in his office, often surviving on potatoes, while making theoretical calculations with almost no resources or access to Western journals. Undeterred by these challenges, he independently calculated the Lamb shift and anomalous magnetic moment of the electron using Tomonaga's formulation of Quantum Electro Dynamics (QED) that came out roughly contemporaneously with breakthroughs by Schwinger and Feynman and was far less celebrated internationally at the time (Brink and Ramond, 2023). This early episode showed not only his intellectual brilliance but also his resiliency and modesty. While others fought for prestige, Nambu remained focused on the integrity of his calculations and the advancement of physics itself.

With progress, professional challenges had taken subtler forms. In the United States in the 1950s and 1960s, Nambu's two revolutionary theories - Spontaneous Symmetry Breaking (SSB) and the Nambu-Joa Lasinio (NJL) model - were occasionally credited to others first. Decades were spent with seminars talking about Goldstone bosons while he sat quietly in the front row, never correcting anyone (Freund, 2016). Humble, believing that science stood above any personal acknowledgment, he manifested ethical restraint and deep respect for collective knowledge. He remained like that even when, despite very early contributions in QED, the Nobel Committee had finally recognized him, in 2008, for symmetry breaking.

2.4 Ethics

Ethically speaking, Nambu's work was steeped in scientific integrity and philosophical reflection. Guided by Mitsuo Taketani's three-stage principle of theory formation, he considered science a moral and intellectual evolution from phenomenology to essential understanding (Freund, 2016). His approach rejected shortcuts or speculation that are detached from empirical meaning. Nambu drew on analogies from superconductivity for his insight into spontaneous symmetry breaking. This stressed continuity between human creativity and the natural order, a point of view which combined scientific discipline with moral humility.

As a mentor and department chair at the University of Chicago, Nambu was patient, quiet, authoritative, and compassionate. He would often avoid confrontation, preferring long silences to saying "no," reflecting both his cultural background and deep empathy (Freund, 2016). His leadership fostered innovation without coercion, therefore freeing students who later became leading physicists. Ultimately, Nambu's professional character was defined not by fame but by perseverance, ethical consistency, and intellectual honesty. He faced neglect and adversity calmly, believing that the truth in science well outlasts recognition. His life is a shining example that there is little inconsistency between humility, integrity, and revolutionary genius.

2.5 Legacy

Yoichiro Nambu's legacy is defined by his scientific breakthroughs and their impact on modern theoretical physics. Nambu's ideas have had large impact on modern research and many experimental discoveries, shaping the way modern quantum and particle physics is studied today. His concept of spontaneous symmetry breaking is directly connected to the 2012 discovery of the Higgs boson. The Higgs mechanism, which is a theoretical framework used to predict the existence of the Higgs boson, was developed by expanding on Nambu's concept of symmetry breaking. Additionally, his theoretical structures are used to this day in many particle physics experiments and models, to explore topics of mass generation, dark matter, and the early conditions of the universe. His insights also extend outside of particle physics, being used to explain phenomena in many other fields including quantum computing, superconductivity, and string theory. The Nambu-Goto string action describes how a one-dimensional object (string) moves through spacetime and acts as a cornerstone of modern string theory (Itoyama, 2016). For his work, he was awarded the Nobel Prize in Physics in 2008. This award is very prestigious, illustrating the groundbreaking nature of his discoveries.

Beyond the direct significance of his work, Nambu was a Japanese-born American physicist, whose impact boosted collaboration between Japan and the USA, and gave much recognition to Japan's global profile in the world of particle physics. Nambu's work is widely referenced and taught in many advanced theoretical physics courses, and Nambu was also a longtime professor at many universities in both Japan and the USA, where he taught and mentored many physics students, helping to shape the future generation of physicists. Yoichiro Nambu's impact and legacy is and will continue to be extremely significant, from his Nobel prize winning theories on spontaneous symmetry breaking, that have led and will continue to lead to many significant scientific discoveries, to his impact on the internationalization of modern physics research, and the many future physicist he impacted with his teaching. It is clear that Yoichiro Nambu's legacy and influence is both long lasting, revolutionary.

Yoichiro Nambu's story is a combination of profound intellect and persistence. His schooling in Japan after the war and his success in American scientific institutions are the main highlights of a lifetime of curiosity and patience. The introduction of spontaneous symmetry breaking by Nambu was a radical shift in the understanding of mass in physics and became one of the key features of the Standard Model. He also contributed the Nambu-Jona Lasinio (NJL) model and the early version of string theory, which were the major breakthroughs in particle physics, directing and sometimes even dominating the research areas as different as superconductivity and cosmology. Theoretical work of Nambu has not only benefited the science of today but also has had an impact on the technologies of tomorrow such as quantum materials and high energy accelerator design.

The main point of this paper is that Nambu was much more than just a solver of mathematical problems. He was the one who made the hidden structures of nature accessible to the scientists. He is still there, not just through the theories he coined, but also through the gentle and humble approach and the discipline with which he sought knowledge.

Once Nambu said: “Nature uses the simplest paths.” His life was a living testament to this idea. Today, even if the universe is still not fully understood and physicists are still looking for the smallest particles and the largest forces to unite, Nambu’s work will always be the guiding light along the way to the most profound understanding of the universe.

3 Lise Meitner (1878-1968)

A Scientist Against the Flow

By Ezra Hill, Lucie Koesen, Murray Boland, Nathan McClinchey, and Palmer Grice

Although often overlooked and forgotten, Albert Einstein himself once praised Lise Meitner as the "German Marie Curie" for her contributions to chemistry and nuclear physics (Sime, 1997). Born in 1878, Lise Meitner was an Austrian-Swedish scientist whose research reshaped the scientific community of the early 1900s. She may not be mentioned often in schoolbooks, but Meitner has made impacts still felt today. From the discoveries of protactinium, the Auger effect (in beta radiation) and nuclear fission, to her work in a war-torn Europe during both world wars, it is no mystery how she received so many awards, nor is it surprising that outrage was sparked when she never won a Nobel Prize.

3.1 Early Life

Lise Meitner's freethinking nature was shared by her family. Notably, all eight of the Meitner children pursued advanced education at a time where that was not the norm. Her father, the chess master Philipp Meitner, was also known to break barriers, being one of Austria's first Jewish lawyers permitted to practice (Sime, 1997). Even at the age of eight years old, Meitner was known to keep a scientific notebook under her pillow, her bright mind apparent at a young age. She attended a school for girls and initially trained to be a teacher, as at the time, it was the only career available to women.

Until 1897, women were also banned from attending public universities in Vienna. When this restriction was finally lifted, gymnasium education requirements were waived for women-only passing matura education was necessary. Inspired by her older sister who passed matura and entered medical school, the ambitious Meitner managed to cram the entirety of the program into two years. In 1901, she was one of four women to pass the matura graduation exam (along with the daughter of Ludwig Boltzmann, a great inspiration to Meitner) (Sime, 1997). This allowed her to enroll at the University of Vienna, where she excelled and became the second woman to earn a doctoral degree in physics at the university. Later, with the encouragement and support of her father, Meitner also attended the Friedrich Wilhelm University in Berlin, where she attended the lectures of the renowned Max Planck (Sime, 1997). Once the Kaiser Wilhelm Institute for Chemistry was established, she obtained her first paid position as a scientific assistant. Although this was very low on the academic ladder, this position made Meitner the first female scientific assistant in Prussian history (Hahn, 1966).

3.2 World War I Era and the Discovery of Protactinium

The assassination of Archduke Franz Ferdinand on June 28, 1914, was the catalyst for World War I (WWI). At this time, Lise Meitner was working at the Kaiser Wilhelm Institute for Chemistry in Berlin, Germany, as an associate, studying radioactivity alongside her collaborator, Otto Hahn. Hahn was called into active service in July of 1914 along with many of the leading scientists. Meitner continued to run the laboratory, working on several projects, including beta spectra and the uranium decay series (Nanal, 2017). She kept a close eye on the long-term project to identify the actinium precursor, always updating Hahn.

Caught up in the wave of nationalism, Meitner volunteered in July 1915 as an X-ray technician for the Austrian army, utilizing her knowledge of radiation. As part of one of the first hospital X-ray units, she witnessed the destruction of the war. The nature of the battle injuries came as a shock, likely contributing to her later refusal to work on the Manhattan Project. She wrote to Hahn saying "... at night, when I lie in bed and cannot sleep right away, I feel slightly homesick for physics, but during the day I think only of the patients ..." (Sime, 1997). Meitner served on the Eastern Front in Poland and the Italian Front.

As the war continued, the German government increasingly used the Kaiser Wilhelm Institute for Chemistry for military research, including chemical warfare. Meitner and Hahn became increasingly troubled by the military's 'appropriation' of their laboratories and offices (Stewart and Rife, 2000). They were concerned that several years of work would be lost. This, coupled with her feeling that she was no longer helpful in her position, led Meitner to seek military discharge. However, she returned to the Institute in October 1916 (Sime, 1997).

Upon Meitner's return, most students, lab assistants, and technicians were still serving in the war. She did numerous aspects of the lab research on her own, including the challenge of acquiring pitchblende (major ore of uranium) samples during wartime restrictions. She returned to prewar research with Hahn, using a military leave to join her at one point. As the newly appointed head of the Physics section of the Institute, she discovered a previously unidentified substance in the decay chain of uranium and, by December 1917, isolated it through chemical separation. It was a missing element on the periodic table. Initially named protoactinium, it was later simplified to protactinium.

When the findings were published in March 1918, Hahn was listed as the first author, despite Meitner doing the lion's share of the work. This could be attributed to a combination of the sexism of the time and her loyalty to her friend, a soldier away from the lab (Sime, 1997). This loyalty would not be reciprocated by Hahn some 20 years later.

3.3 Research on Beta Radiation

Meitner is known to be one of the leading researchers into beta decay, a pioneer of the field (Mahnke, 2022). Beginning her research in 1906, she built her reputation on turning the vague problem of Beta rays into a careful program of measurements and analysis (Kubbinga, 2019). She helped to describe how nuclei behave, first with Hahn in Berlin (Kubbinga, 2019). She moved beyond simple absorption tests, bending electron beams in magnetic fields, and using their paths as clues to the particle energies (Kubbinga, 2019). Measurements consistently showed that as the field curved the streams, both a smooth spread of beta energies, and narrow, distinct, repeatable lines superimposed on the continuum were visible (Mahnke, 2022). This made it clear that beta radiation was not uniquely a discrete or continuous phenomenon, but rather a layered signal of both (Mahnke, 2022). These sharp lines helped to build her research into "internal conversion", a process where excited nuclei give energy to their electrons rather than directly emitting gamma rays, producing electrons with specific energies (Mahnke, 2022). Essentially, she transformed the field of study from "detecting" beta radiation to a rigorous system of decoding the nucleus, shifting the tone for later spectroscopy research (Kubbinga, 2019).

Her work on internal conversion would continue into the early 1930s; using the discrete electron lines, to pin down specific nuclear steps, while separating them from the broad beta decay continuum (Mahnke, 2022). As her methods matured, conversion electron spectroscopy became the standard diagnostic tool to identify the kind of change the nucleus made, and the basic properties before and after (Mahnke, 2022). When political pressure forced her to move from Berlin to Stockholm in 1938, she carried that spectroscopist's toolkit into exile, laying groundwork for the transmutation questions that came in the next period of her life (Kubbinga, 2019).

3.4 World War II Era and Transmutation

Lise Meitner made important advances to our understanding of atomic structure and element transmutation during World War II (WWII), work that would later be essential to nuclear research. Meitner researched transmutation, the process by which atoms of one element could change into another through radioactive decay, both before and during the war. She found that unstable atomic nuclei changed their identity by releasing energy and particles. Meitner studied the unexpected production of lighter elements like barium when uranium was bombarded with neutrons while working with Otto Hahn in Berlin. She continued to examine the findings from exile in Sweden after escaping Nazi Germany in 1938 (Sime, 1997). She was able to escape just after the Nazi's introduced a policy prohibiting all scientists from leaving Germany. She was able to secure the proper documentation to travel and cross the German border into Holland until she eventually took refuge in Sweden. While in Sweden she was able to correspond with Hahn through letters to continue their research.

The early research on transmutation by Meitner and Hahn was to better understand how one element could change into another, Meitner's research tracked the particles and energy produced during these changes. She finally co-discovered nuclear fission, one of the most significant advances in atomic physics, thanks to her early research on isotopes and the emission of alpha and beta particles, which paved the way for later discoveries in artificial transmutation.

3.5 Nuclear Fission

Lise Meitner's contributions to the discovery of nuclear fission did not include performing the final experiments but rather composed of letters and correspondence with her former team where she would give advice and help to Otto Hahn and Fritz Strassmann. For example, Hahn and Strassmann conducted an experiment that fractionated uranium and produced barium. Their previous research alongside Lise Meitner assumed that uranium would form transuranium elements (elements heavier than uranium) when bombarded with neutrons rather than lighter elements like barium (Sime, 1997). The transuranium elements are the chemical elements with atomic number greater than 92, which is the atomic number of uranium. All of them are radioactively unstable and decay into other elements. Before receiving a reply from Lise Meitner, Hans wrote a flawed paper assuming the products of uranium splitting would have the same atomic weight, but their assumed products had the incorrect number of protons (barium and madelungium). In Otto Robert Frisch's memoir, Lise Meitner's nephew, he recalls meeting his aunt around Christmas mulling over a letter from Hahn. The two talked about the research and Lise knew that the protons in the products would have to be the same so leading to products of barium and krypton. The change in atomic weight is attributed to the difference in packing fraction between uranium and the elements in the middle of the periodic table, with mass being converted to energy according to Einstein's equation

$$E = mc^2. \tag{3.1}$$

Lise would proceed to write to Hahn and explain that their assumed products are incorrect and brought up performing a joint retraction to their previous research on transuranium elements (Sime, 1997). This demonstrates Lise Meitner's ability to contribute to the research of nuclear fission despite being unable to perform the required experiments herself.

Lise Meitner would continue to give ideas for experiments and aid Hahn with their research but when Hahn and Strassmann eventually write their paper on their barium proof and fission products, they only include a paper from Meitner and Frisch as a postscript despite Lise Meitner's close collaboration throughout all the research. The reason why Hahn and Strassmann could not credit Lise Meitner as much as she deserved is because she was a refugee of Nazi Germany and including her in the paper could put their institution at risk (Sime, 1997). Even though Lise continued to credit Hahn when he was away as a soldier, Hahn did not do the same for Lise when they were not physically present for their research.

3.6 Long Term Impacts, Reflection and Conclusion

The legacy of Lise Meitner extends far past her discoveries in nuclear physics. From her early work on protactinium and beta radiation to her role in dissecting nuclear fission, Meitner helped lay the foundation of atomic science as it is known today. Just as notable as her intelligence was her integrity-she did not compromise her principles even when faced with war, exile, and discrimination. She understood that knowledge should be used to help humanity rather than destroy it: hence, her adamant refusal to work on the Manhattan Project, even when invited to. On Meitner's headstone, her nephew engraved a fitting inscription: "Lise Meitner: a physicist who never lost her humanity" (Sime, 1997).

4 George Boole (1815-1864)

A Genius Unrecognized in Life

By Jackson Phillips, Ahmed Imtiaz Rais, Farah Suleiman, and Jeffrey Olijnyk

A truly groundbreaking idea is so bizarre that in comparison to what already exists it is indistinguishable from incoherent rambling. The work of George Boole fits this description. His unique position as a self-taught academic lead him to developing an equally unique perspective on mathematics and logic compared to his contemporaries. Ultimately the work he produced was so ahead of its time that the intellectual community was incapable of recognizing it as the foundational theory behind modern computer logic, the technology that would define the modern world. This essay will first investigate the factors that lead to Boole's unique perspective that enabled his academic work. This will be followed by a review of peer responses to Boole's most influential work. Lastly, a look at a modern reflection of Boole will be used to highlight the discrepancy between the two interpretations ultimately showing the seemingly bizarre can actually be genius.

4.1 The Beginning

Geroge Boole, an English mathematician, helped establish modern symbolic logic, which is now called Boolean algebra and is basic to the design of digital computer circuits. He was given his first lessons in mathematics by his father, who was a tradesman, and taught him how to make optical instruments. Boole was self-taught in mathematics, aside from his father's help and a few years spent in local schools. He had to work to support his family when his father's business declined. From an early age of 16, he taught in the village schools in the West Riding of Yorkshire, and later opened his own school in Lincoln, England, his hometown, at the age of 20. During his free time, he would read mathematics journals in the Lincoln's Mechanics Institute. There he read several books like Issac Newton's *Principia*, Pierre-Simon Laplace's *Traité de mécanique céleste*, and Joseph-Louis Lagrange's *Mécanique analytique* and began to solve advanced problems in algebra.

"Even as a young boy, George experienced the joy of practical scientific creations through his father's passion for optics and astronomy. Together they built cameras, kaleidoscopes, microscopes, telescopes, and a sundial. There is a story that they even attempted to construct a primitive calculating machine. Although George was later to become one of the greatest mathematicians of the age, he never lost sight of the fact that much of mathematics had its origins in the search for solutions to practical scientific problems, with the result that for the rest of his life he retained a lively interest in such applications of mathematics. Nevertheless, the fact that he was exposed from a very early age to the mysteries and techniques of elementary pure mathematics must also have had a profound effect on his mental development (MacHale, 2014)."

This quotation from the book *The Life and Work of George Boole: A prelude to the Digital Age* explains how George Boole was exposed to mathematics at a very young age, which sparked his interest in learning more about mathematics and its applications to his and his father's work in optics. These experiences had a strong impact on his mental development and later led him to become one of the greatest mathematicians of his time. In addition, because Boole was self-taught in mathematics and did not attend an institution to gain knowledge in this subject, he was able to think creatively and experiment with new ideas without the pressure of following strict academic methods. Being introduced to mathematics so early also helped him develop strong critical thinking skills, which became part of his personality and shaped the way he approaches problems throughout his life.

4.2 Influential Work

As a professor, Boole published several works on calculus and differential equations, which lent credence to his intellectual reputation and skill. However, Boole's most groundbreaking work would be, *The laws of Thought*, although no one at the time would have any idea of its future importance. It was viewed as a bizarre framework that laid out an algebra based system of logic he envisioned to bring a math-based approach to logical thinking. He sought not to replace classical Greek philosophy but to mathematize it. Since there were no computers or practical use of his work, it was largely ignored by the scientific community at the time. A contemporary mathematician of Boole at the time, named William Stanley Jevons, disagreed with the usefulness of Boole's work. In 1870 Jevons discusses the *The laws of thought*, critizing the complexity of the symbols used, while also discounting the actual applications of it as basic (Jevons, 1870). Here is a quote

"I endeavoured to show in my work ... [*Pure Logic Or The Logic Of Quality Apart From Quantity*] that the mysterious mathematical forms of Boole's logic are altogether superfluous, and that in one point of great importance, the employment of exclusive instead of unexclusive alternatives, he was deeply mistaken. Rejecting the mathematical dress and the erroneous conditions of his symbols, we arrive at a logical method of the utmost generality and simplicity (Jevons, 1870)."

Although Jevons took the time to study Boole's work, he walked away with a strong criticism of its applicational uses. He describes the symbols as mysterious and the overall system as one that is only useful for the simplest of tasks. It is ironic that he disregarded the importance of Bool's work and would have been shocked to know that it was that level of abstraction which provided a backbone for modern logical computing. The dismissive reaction to Boole's ideas shows that abstract, out-of-the box approaches to knowledge, and problem solving are met with skepticism, and that practical value is not obvious until it can be applied. The irrelevance at the time was not caused by an error in Boolean logic, but technology at the time was not yet advanced enough to need them.

4.3 Legacy

Years after his death in the 1930s the first computers were being designed. At this point Boole's work was finally becoming useful in a practical setting, and would go on to be the underlying theory dominating the logic of all computers and even modern artificial intelligence systems. In the mid to late 1930s engineers were working on relays and switching circuits, which are a network of on/off electrical switches used to make simple decisions in a system. Claude Shannon, a mathematician, was able to demonstrate how Boole's algebra could be used to design and simplify the relay and switching circuits in his MIT master's thesis which was published in 1938. Many people argue that this realization helped to transition the task of computer circuit creation from trial and error towards the unique engineering sector that it is today and that it provided an essential component in the blueprint of modern computer circuits. This meant that simple statements like "and, or, and not" could be built directly into the hardware, which is why future machines were mainly based on this Boolean logic. From a historical perspective, Boole's "laws of thought" discussed in his book published in 1854 aided in the vast advancement of the digital world. It is also evident that this logic and Boolean algebra is still essential for modern day electronics and is used in various programming and artificial intelligence platforms. This shows that the ideas many of Boole's peers ignored at the time are now the main component in the majority of the modern electronics, and will continue to shape future advancements in technology for years to come.

The life and legacy of George Boole demonstrate that the great ideas are not always seen as such. Often, they may even seem strange, impractical and useless. Boole's unorthodox education shaped a mind that did not accept limitations and assumptions about the way things had to be. Where his contemporaries dismissed his work as an abstract thought exercise, he saw the potential for its use in contexts not yet fully understood. In hindsight, looking back from the modern era George Boole was not just an 1800s scholar but an intellectual precursor to modern computing logic.

5 Subrahmanyan Chandrasekhar (1910-1995)

Between Gravity and Light

By Andrew Brown, Cody Miault, Gavin Penny, and Aedan Sheehan

5.1 Introduction

Subrahmanyan Chandrasekhar was an astrophysicist whose work changed how we understand the life and death of stars, from the stability of white dwarfs to the formation of black holes (Dyson, 2010). This essay examines his life and career to show how personal background, education, and working conditions can shape scientific ideas. It follows his path from his early years in India, through his university and PhD studies in Cambridge, to his later research and teaching at the University of Chicago, highlighting key moments such as the development of the Chandrasekhar Limit, the controversy it created, and his later work on stellar structure and black holes (Tayler, 1996). By tracing these stages, we consider not only what Chandrasekhar discovered, but also how his disciplined, patient approach to physics and his response to criticism shaped his contributions.

In doing so, the essay reflects on what his life can teach engineers and scientists today about perseverance, integrity, and the connection between technical work and its broader human context.

5.2 Early Life and Upbringing

Subrahmanyan Chandrasekhar was born on October 19, 1910, in Lahore, which was then part of British India and is now located in Pakistan. He grew up in an intellectually strong family that placed a high value on education and the sciences. His mother Sitalakshmi Ayyar played an important role in shaping her son's interest in learning, while his father, C. Subrahmanyan Ayyar, worked as an official in the Indian Audit and Accounts Service. Before he even began schooling, his mother guided his learning, teaching him math and Sanskrit. Chandrasekhar later acknowledged that his strict study habits and deep respect for education came from his mother's influence.

His uncle, the famous physicist C. V. Raman, who would later win the 1930 Nobel prize in physics discovering the Raman phenomenon, had a major impact on him as a young man. Exposure to Raman's research and the academic atmosphere of his extended family inspired Chandrasekhar to pursue physics with the same intensity. He was reading advanced scientific articles by the time he was a teenager, and out of pure curiosity, he was copying mathematical derivations from them.

After graduating from Hindu high School, Chandrasekhar enrolled in Presidency College in Madras (now called Chennai). He quickly became known as an intelligent and a hard-working student. He used quantum mechanics to analyze Compton scattering in his first research work, which was published while he was still an undergraduate student. This was a remarkable achievement for someone who was only 20 years old (Chandrasekhar, 1987). He also learned about the most recent advancements in quantum theory and relativity at Presidency College which would influence his future career. Even with few resources and the limits placed on Indian universities at the time, he stayed focused on doing his best.

His family's guidance, independent thinking, and early interest in science shaped his early years. His upbringing taught him physics as well as the discipline and determination that later led to his major discoveries.

5.3 University and PhD Research

As Subrahmanyam's life progressed, his curiosity and willingness to learn stayed with him. With early success in the field of academia, he kept on going, delving into his field of study with a particular vigor for mathematics and physics. This passion was further driven after his undergraduate studies as he pursued a PhD. However, with the limits placed upon him in India, and India still being a part of the British Empire, in 1930, he left his homeland to go to the prestigious University of Cambridge.

As he voyaged to his new home upon the S.S. Pilsna, Chandrasekhar began developing his first theory, known as the Chandrasekhar Limit. Utilizing the newly created theory of relativity, he looked upon the stars while aboard the ocean liner and thought of the mysterious white dwarf star. It was here he first pondered his theory, which posed the maximum limit of a white dwarf star to be 1.44 times the mass of our sun, beyond which it would go supernova. This eventually led to the conceptualization of a new, broader theory, which, using his extensive mathematical repertoire, suggested that his previous theory fit all stars, not just white dwarfs. In this, he posed that after a star reached the Chandrasekhar Limit, its mass would be too large, thus its gravitational force too strong, and the electron degeneracy pressure could be overcome, causing collapse and evolution into a neutron star or a black hole (Chandrasekhar, 1992).

This theory was hard for the scientific community to accept and received plenty of push-back initially from many figures within the community. Although Subrahmanyam pushed on pursuing his PhD, and under the supervision of the infamous R.H. Fowler, he honed his mathematical prowess. Continuing upon his early works, he focused on the structure of stars, applying his knowledge of quantum statistics to the field of astrophysics. Using this new statistical approach, he relentlessly developed equations to describe compact star formation from 1931 to 1935, publishing along the way in the *Monthly Notices of the Royal Astronomical Society*. Eventually culminating in his PhD with 4 years of calculations compiled in his dissertation, which would go on to set the basis for the modern theory of star evolution.

At the age of 26, Chandrasekhar finished his PhD, taking with him a newfound respect and admiration for the beauty and symmetry of the mathematical world. This philosophy is one that he took with him throughout his life, finding beauty in the harmonious and complicated structure of the universe, which is what ultimately drove his pursuit to unlock its secrets. This fascination with the aesthetic nature of science was realized during his PhD studies and would later on inspire him to write one of his many books, *Truth and Beauty: Aesthetics and Motivations in Science* (Chandrasekhar, 1987). This shows his dedication and passion for discovering the unknown, and utilizing his knowledge of physics and mathematics, he continued to chase this passion throughout his life.

5.4 Later Career and Activities

After finishing his PhD, Subrahmanyan Chandrasekhar began a lifelong career at the University of Chicago. He joined the faculty in 1937 and remained there for nearly sixty years, becoming one of the most respected theoretical astrophysicists of the twentieth century. In his first years at the University of Chicago, he focused on studying how stars are structured and how energy moves within them. His books *An Introduction to the Study of Stellar Structure* (Chandrasekhar, 1939) and *Radiative Transfer* (Chandrasekhar, 1960) helped establish a clear mathematical method for explaining how radiation and matter interact in stars (Tayler, 1996). These works laid the foundation for a new level of precision in astrophysical modeling and are still recognized as landmark texts in the field. As his career developed, Chandrasekhar continued to expand the scope of his research. In the 1950s and 1960s, he studied problems involving fluid and magnetic stability, which led to the publication of *Hydrodynamic and Hydromagnetic Stability* (Chandrasekhar, 1981). His approach to these topics reflected his characteristic combination of mathematical rigor and physical insight. By focusing on the stability of fluids under different forces, he advanced understanding of turbulence, convection, and magnetized flows, all of which are central to many areas of astrophysics (Wali, 1990).

Chandrasekhar also played a major role in shaping the scientific community through his editorship of *The Astrophysical Journal* The Astrophysical Journal, a position he held from 1952 to 1971. Under his leadership, the journal became one of the most respected in the world (Tayler, 1996). He set an incredibly high standard for scientific publishing through his commitment to accuracy and thoughtful review. Despite the demanding nature of this role, he maintained a remarkable pace of personal research and publication. His ability to balance editorial responsibilities with groundbreaking work showed the discipline and precision that defined his entire career.

In the later parts of his life, Chandrasekhar turned his attention toward general relativity and the mathematical theory of black holes. His 1983 book, *The Mathematical Theory of Black Holes* (Chandrasekhar, 1992) became an important reference for the subject. That same year, he was awarded the Nobel Prize in Physics, shared with William Fowler, for their theoretical studies on stellar structure and evolution. Even in the later years of his life, he continued to publish and teach, remaining an active and influential figure in astrophysics until his death in 1995.

Chandrasekhar's career is remembered for its extraordinary depth, discipline, and intellectual honesty. He was known for approaching every problem with careful logic and an appreciation for mathematical beauty. His ability to move between different scientific areas while maintaining the same level of rigor and creativity made him one of the most versatile scientists of his generation. His legacy continues to influence modern astrophysics and serves as an example of lifelong dedication to discovery.

5.5 Conclusion

Subrahmanyan Chandrasekhar's achievements grew out of more than natural talent. His childhood in Madras gave him a sturdy base of family support, self discipline, and curiosity. Guided by his parents and influenced by relatives, he learned to treat study as a serious daily activity and to rely on his own reading and problem solving (Tayler, 1996). That foundation helped him adapt when he moved from India to Cambridge and entered a vastly different academic culture.

As a young researcher, he combined new quantum ideas with classical physics to study the structure and fate of stars. His work, on what is now called the Chandrasekhar Limit, showed that very massive white dwarfs cannot remain stable and must collapse further, a result that many senior scientists found difficult to accept. The criticism he faced did not end his career. Instead, he shifted his focus while keeping the same lofty standards of clarity and mathematical rigor, and he went on to make important contributions to stellar structure, radiative transfer, and black hole theory. In his later years at the University of Chicago, his teaching, his textbooks, and his demanding editorship of *The Astrophysical Journal* helped shape expectations about what careful and honest scientific work should look like (Wali, 1990).

Looking back on Chandrasekhar's life, it is clear that his impact cannot be measured only by the number of papers or prizes he received. His story shows how a supportive learning environment, personal discipline, and a commitment to intellectual honesty can influence the direction of an entire field. For engineering students, his example suggests that how we work can matter as much as what we discover. It encourages us to approach technical problems with patience and precision, to respond thoughtfully to criticism, and to remember that the methods and values we bring to our work will affect both our results and the people who rely on them.

6 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 associate professor in the Department of Mechanical Engineering, College of Engineering, at the University of Guelph, Canada. He is specialized in environmental thermo-fluids, finance, economics, and externalities. 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.

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