The Walk of Life

Biographical Essays in Science and Engineering

Volume 2

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Perhaps some day in the dim future it will be possible to advance the computations faster than the weather advances and at a cost less than the saving to mankind due to the information gained. But that is a dream.

—Lewis Fry Richardson

Dedication

Zinat Saeb

Preface

The essays in this volume result from the Fall 2017 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 Lewis Fry Richardson, Giovanni Battista Venturi, Jean Baptiste Perrin, Edgar Buckingham, Lorenzo Romano Amedeo Carlo Avogadro, Jean-Baptiste Joseph Fourier, Ludwig Prandtl, and Geoffrey Ingram Taylor. Figures in this list are less well-known and written about compared to the previous volume. Nevertheless, 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

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

Amir A. Aliabadi

Contents

1 Lewis Fry Richardson (1881-1953)

The Young Genius

By Katherine Gatzos, Tanya Leers, Noah Thompson, Allison Cox, and Haley Birrell

Lewis Fry Richardson was a man who was moulded by the influences of various people throughout the early stages of his life. Richardson is highly regarded for his discovery of using a numerical method that forecast weather and his interests in science can be traced back to an age as young as five. The early stages in Richardson's life were big reasons as to why he could achieve his various discoveries while playing a significant role in the person he became and the morals he lived by.

Lewis Fry Richardson was born on October 11, 1881, in Newcastle to mother Catherine Fry and father David Richardson. His passion for science began at the early age of five when he became very interested in electricity and how it worked. At the age of ten his interest grew into the focus of chemistry, which may have been due to the influence of family friend Henry Richardson Procter. Procter eventually became the head of the applied chemistry department of Leeds University (Schultz and Knox, 2013).

Richardson enrolled in the Bootham School in York in 1894, which was a Quaker boarding school. The combination of discipline and excellent teaching produced a flourishing young man for the four years he attended Bootham. James Edmund Clark, one of Lewis' masters, was a member of the Royal Meteorological Society. Richardson had commented on how Clark gave them a good incite on the wonders of science (Schultz and Knox, 2013). The eye-opening impact Clark had on Richardson's life at such a young age could have been a major reason as to why he took such an interest in meteorological studies.

When observing the early life of Richardson, there are some defining reasons why his pacifist views were created. Looking at the way he was raised within his family and the school he attended gives a better understanding for devoting his later life to the study of causes of war. Richardson was born into a long bloodline of Quakers which was a Religious Society of Friends and Bootham was a Quaker boarding school. He was a conscientious objector during the World War I (WWI), where he worked with an ambulance convoy in France. His desire to abstain from war were found in his notes, that talk about the religious obligation and Christ's teaching about war and violence. As a result, his convictions held true and he felt that the teachings of Christ and war did not align. His convictions were so strong that he resigned from the meteorological office after they joined the Air Ministry which was indirectly associated with the armed forces in which he did not want any part with (Richardson, 1957). When taking a closer look at the early life of Richardson, it is evident that the way he was raised instilled most of his morals that carried out through a majority of his life.

1.1 The Meteorologist

Among Richardson's many accomplishments, his advancements in meteorology is the greatest. In the early 1900s, when Richardson first showed an interest in meteorology, scientific progression in weather forecasting was limited. At that time, forecasts were predicted using a combination of semi-empirical equations in conjunction with a series of analogue methods. Many scientists, including Felix Exner, Cleveland Abbe, and Vilhelm Bjerknes challenged these methods, all having understood that forecasting should be based on a series of mathematical equations which represent the physical processes of the atmosphere (Charlton-Perez and Dacre, 2011).

Richardson, like the others, sought out to develop practical methods to solve weather forecasts and after years of tiresome and rigorous work, he succeeded. Using a system of grid points distributed over the earth's surface, Richardson was able to develop a series of primitive equations which could be solved to determine the weather at a particular location and time. In order to test his theory, using nothing but a mathematical model of the atmosphere and a rudimentary calculator, Richardson attempted to forecast the humidity, pressure, and stratospheric temperature over central Europe. Using weather data taken at 4:00 A.M. on May 20^{th}, 1910, Richardson predicted the forecast for the weather six hours later. At first glance the prediction appeared significantly incorrect, however, after a detailed analysis was conducted, it was concluded that if the scientist had applied smoothing techniques to his data, his forecast would have been accurate (Vulpiani, 2014). This was an astonishing achievement at the time, as his calculations were performed by hand, considering the fact that present day forecasts are made possible using super computers.

During this time, Richardson had calculated that in order to predict the weather for the following day, at least 60,000 people would be needed in order to perform the calculations. At this time, although a computing device had not yet been developed, Richardson was optimistic that "perhaps some day in the dim future it will be possible to advance the computations faster than the weather advances and at a cost less than the saving to mankind due to the information gained. But that is a dream" (Richardson, 1922).

In 1922 Richardson published *Weather Prediction by Numerical Process*, a series of papers outlining the detailed algorithm for systematic numerical weather prediction. It wasn't until 1950 when Electronic Numerical Integrator and Computer (ENIAC), the first modern computer, was developed that any other significant advances had been made in this field. The computing power of ENIAC was able to perform the calculations for a 24 hour forecast in approximately 24 hours; an enormous scientific advancement according to Richardson.

Lewis Fry Richardson is recognized for his astonishing advancements in weather forecasting and although greatly ahead of his time, Richardson's "great, visionary notion for weather forecasting" (Vulpiani, 2014) is fundamental to present day weather predictions. It is truly unfortunate that this brilliant scientist never got to see the evolution of weather prediction, as it was only one year after Richardson died, that British Broadcasting Corporation (BBC) would air the first weather forecast television programme.

1.2 The Atmospheric Scientist

In order to create a numerical method of forecasting weather, Richardson knew that he needed to improve his knowledge of mixing in the lower atmosphere (Hunt, 1998). He conducted many experiments in atmospheric science, many involving turbulent motion. He studied eddy dispersion by measuring the width of smoke plumes and the separation between balloons or seeds released into the air. He used these experiments to derive the law for the rate of dispersion often referred to as the four-thirds law. This law states that the rate of diffusion between objects in a turbulent stream increases proportional to their separation raised to the power of 4/3 (Hunt, 1998). This discovery suggests that turbulent flow is composed of eddies of varying length scales and inspired one of Richardson's famous quotes based on the poet Johnathan Swift: "Big whirls have little whirls that feed on their velocity, and little whirls have lesser whirls and so on to viscosity—in the molecular sense."

To characterize turbulence at different times, Richardson observed fluctuations in wind speed at two heights (Hunt, 1998). He analyzed how the fluctuations at each height were affected by the difference in the two air temperatures and wind speeds (Hunt, 1998). It was determined that when the difference in temperature between the two heights was greater, i.e. temperature aloft was higher than the one below, the fluctuations in the wind speed decreased at both locations (Hunt, 1998). This suggested that the atmosphere was more stable and had less turbulence under such conditions. These observations could be related to the energy in eddies created from buoyant forces. These forces resulted in eddies of different temperatures moving to different levels of the atmosphere due to their different densities and therefore buoyancies (Hunt, 1998). In addition, when the difference in wind speeds is increased between the two heights, the fluctuations increase. This allowed Richardson to understand the contribution of the force of accelerations of eddies moving between levels of higher and lower wind speeds (Hunt, 1998).

Richardson was able to use his new understanding of these forces to estimate the role each one played on providing energy to eddies. He represented his finding in a ratio between buoyant and flow shear forces, which was later named Richardson number in his honour. The Richardson number is defined as $Ri = g\nabla\rho/(\rho(\nabla u)^2)$, where g is gravitational acceleration, ρ is air density, and u is air velocity in the horizontal direction. When Richardson number is greater than one, then the turbulence is suppressed, and when less than one, then the turbulence is unsuppressed. The number is positive if the atmosphere is stable and negative if unstable. Richardson's number is just one example of his lasting impact on the field of atmospheric science and turbulent motion.

1.3 The Pacifist

Passionate, brilliant, and pacifistic are just some of the words that can be used to describe Richardson. Unlike the stereotypical scientist or engineer at the time, he had a very empathetic and philanthropic outlook on life. Mathematically, he developed fundamental laws that are still used to this day in engineering, physics, calculus, and other sciences. Richardson had very strong beliefs about war and killing, so much so, that he prided himself as being a pacifist almost before calling himself a mathematician. Imagine trying to model the behaviour of humans through equations. Well, this is exactly what Richardson did. He believed that societal interaction could be explained through mathematical principles and the application of pre-existing laws of physics. For example, the laws that govern conservation and constitution. This is where his true greatness was not as recognized as much as it should have been at the time since his work was only partially published.

During the outbreak of WWI, his thoughts were consumed with the potential causes of violence and how it could be explained. As a result of this fascination, he wrote a manuscript called *Reflections on War and the Conditions of a Lasting Peace in Europe*. This text consists of two essays on the issue of war. The first essay is Richardson's personal critique of Abbe Saint-Pierre's ideas. Saint-Pierre aimed to prove that the prospering of a European Federation would end the possibility of war from occurring. Richardson then attempted to formulate his own theory of what can be considered a 'just war'. The timing of this text was poignant as it was released near the end of WWI. This allowed for societal reflection on what one may consider to be just in a war, and the conditions that make for the sacrifice of a nation and life worth the cause.

Richardson also developed a fascination with biblical teachings and its views on war. This is rather interesting and somewhat ironic since throughout history, scientists often discredited a lot of religion, and vice versa. Richardson adopting some beliefs from the bible to assist in the development of his mathematical theories, is almost a peace offering in itself.

One of his most prevalent theories he developed to explain war was the *Deterministic Theory of Arms Races*, where he applied some of the governing equations he developed earlier for his numerical weather prediction model. However, his biggest challenge arose when he learned that war and peace were neither conservation nor constitutive equations. Thus, he developed a heuristic model. The first and foremost assumption adopted the use of Occam's razor, where large-scale human relations were partly subject to choice and partly subject to pre-determination. In other words, one variable could be influenced (dependent) and the other could not. Richardson did not stop here, he continued to utilize different variables, differential equations, and matrices to measure a country's level of defence. The development of the arms race model exhibited a beautiful and complex mathematical frame work that fundamentally made sense. Richardson's ability to intertwine the beauty and logic of mathematics with the world's major suffering is extremely commendable and rather inspiring.

1.4 The Visionary

Lewis Fry Richardson accomplished great achievements throughout his life time. From mathematical theories, to weather forecasting, to his strong beliefs and principles on war, he is no doubt an incredibly inspirational person. By imagining a world where people could be religious and scientific simultaneously, is commendable in its own right and something that historically has always been contradictory. All in all, Lewis Fry Richardson was a true visionary and will be remembered for many years to come.

2 Giovanni Battista Venturi (1746-1822)

A Key Foundation for Modern Day Hydraulics

By Jacob Bates, Jessica Wagner, Erist Wame, and Lauren Whyte

The second half of the eighteenth century was a tumultuous time in recorded history. This period was marked with intense struggle between the working class and gentry, which culminated in the French Revolution in 1789. The political ideals of 'Liberty, Equality, and Fraternity' produced the Declaration of the Rights of Man and of the Citizen, confirming the rights of every man, abolishing the French monarchy, and signalling the eventual divide of Church and State. However, with a new focus on Enlightenment ideals came the promotion of science and intellectual interchange, allowing brilliant minds to flourish. One such thinker was Giovanni Battista Venturi, whose life and works will be examined in the following pages.

2.1 Life and Career

Venturi was born in 1746 in Bibbiano, a village in the province of Reggio Emilia, northern Italy (Kent, 1912). Bibbiano is approximately 80 km from Bologna, which was a major centre for learning at the time. Venturi was born into a well-off family and was therefore able to attend school at a local seminary. He was ordained a priest at 23 and taught at the seminary that he had attended as a child for five years (Soto-Ruiz et al., 2011). In 1774, he was asked to teach geometry and philosophy at the University of Modena. After several years of teaching at the University, Venturi earned the attention of the Marquis of Rangone, Minister to the Duke of Modena, Ercole III d'Este (Kent, 1912). This favour allowed him to be promoted to State engineer where he was involved in the building of bridges, remediation of watercourses, and the establishment of state regulations for dam construction. In 1786, he was made a Professor of Experimental Physics at the University of Modena, where he was finally able to access the resources to study his interests.

In 1793, Venturi was sent to Paris by the Duke of Modena to act as an ambassador for Italy at the Supreme Executive Council. This was because the newly minted First French Republic declared war on the Hapsburg Monarchy of Austria on April 20, 1792, and due to its geographical position between France and Austria, Northern Italy became a battleground for the French Revolutionary Wars. Therefore, ambassadors from Italy were sent to France to represent the interests of their country which was caught in the crossfire. After largely unsuccessful negotiations with the French, Venturi stayed in Paris to continue his study of physics and chemistry and met contemporary math and science minds such as Cuvier, Hauy, Biot, Lalande, Monge, and Laplace, among others (Kent, 1912). While in Paris, he published works such as: *Experimental Researches on the Principle of the Lateral Communication of Movement in Fluids Applied to the Explanation of Different Hydraulic Phenomena* as well as discussions on Leonardo da Vinci and Galileo's works. Jerome Lalande, a French astronomer and Director of the Paris

Observatory, commended Venturi to General Napoleon Bonaparte "as one of the men most competent to bring renown to Italy and to build there useful waterworks and do good work in mathematics and physics," and praised him for his "ability in the art of civil engineering and military architecture" (Kent, 1912).

While he was away from his post at the University of Modena, many of his contemporaries tried to remove him from his position due to his association with the French. By this time (1796), Modena was occupied by the French army under Napoleon, who deposed the Duke and created a Cispadane Republic (Nicassio, 1992). It was likely that Venturi's colleagues at the University were displeased with his duplicity as an Italian living in luxury in France while occupying a position at the University. However, Venturi took advantage of his favour with Bonaparte who made him a member of the Corps Legislatif, professor at the Military School of Modena, as well as a Chevalier of the Legion of Honour. Continuing jealousy of his peers and political issues subjected Venturi to a time of hardship, eventually leading to his imprisonment in Modena for fraternizing with the French (Kent, 1912).

In October of 1797, Austria signed the Treaty of Campo Formio, which ceded Belgium to France and recognized French control of the Rhineland and the majority of Italy. In 1799, Napoleon, now named First Consul of the Republic, gave Venturi a professorship at the University of Pavia; and, in 1800 he was made Diplomatic Agent of the Helvetic Confederation, which was essentially a Republic imposed by the French on Switzerland (Kent, 1912). Venturi spent the next twelve years in Switzerland as a diplomat, which allowed him to continue his scientific study. He retired to his hometown of Reggio in 1813 as a result of poor health, and was granted the maximum pension allowable by the Emperor Napoleon. There he continued his vocation, publishing several scientific and literary works, specifically *Commentaries on the History and Theories of the Optician* in 1814.

2.2 Mathematics, Physics, What Else?

From his experiences as a priest, professor, diplomat, and statesman, Venturi had the opportunity to establish himself as a true renaissance man. Not only did he enjoy general mathematics and physics, he was distinguished by his work on hydraulic systems and was one of many that paved the way for modern day fluid dynamics. It was during his time in Paris after negotiations fell through between Italy and France that he started experimenting with hydraulics. One of his two main experimental journal articles published were on da Vinci, who had completed experiments involving hydraulics. It appears that da Vinci was an inspiration to Venturi for his comprehensive understanding of natural phenomena. His other main published article, *Experimental Researches on the Principle of the Lateral Communication of Movement in Fluids Applied to the Explanation of Different Hydraulic Phenomena*, had several experiments within, most notably one where he observed water flow through pipes and discovered that the properties change as the cross-sectional area changes (Soto-Ruiz et al., 2011). If water is moving through a pipe and reaches a convergence, he noted that the velocity increases as the pressure decreases, which is consistent with the continuity equation and Bernoulli's principle. This had many impacts on the way hydraulics was understood. Prior to this discovery, flow was measured with a Pitot tube, which was invented in 1732 by the French hydraulic engineer Henri Pitot.

Even though Venturi had published a ground-breaking article communicating his findings, none of it was used outside of a laboratory until the late 1800s. His ideas were first uncovered by Clemens Herschel, an American hydraulic engineer. Venturi's original experiments involved a large apparatus, which Herschel modified, to construct the Venturi Tube, measuring the volume of water flowing through it by using a pair of manometers.

This was just one great experiment; he had many other breakthroughs within this series, all outlined in his research journal, *Experimental Researches on the Principle of the Lateral Communication of Movement in Fluids Applied to the Explanation of Different Hydraulic Phenomena*. One of his other discoveries was based on the velocity profile of streams in conjunction with eddies of these streams. His experiment was laid out to demonstrate that faster moving water located near the middle of the channel communicates with its latter counter parts (near the banks). Da Vinci and Bernoulli both had uncertainties about this topic in terms of eddy formation. Venturi demonstrated this uncertainty and showed that turbulent waters influence slower moving waters on the banks and sides of streams (Tredgold, 1836).

In addition to his experiments with hydraulics, Venturi was interested in the auditory capability of a person's ear with respect to localization. Experiments and studies are thought to begin with Venturi's initial investigations into this topic. He started by studying the effects of listening to an instrument with one ear blocked by a finger over a differential distance. From this, it was concluded that the person could only locate the sound when it was on the same plane as the uncovered ear, which was determined to be the 'auditory axis'. Other experiments were conducted and explained that when both ears are open, there is some accuracy with locating noise, but the auditory axis is essential when one ear is covered.

2.3 Still Relevant

Venturi died in 1822 at the age of 76. He may not be as well-known as other great minds of his day such as Sir Isaac Newton (1643-1727), but his experiments and inventions rippled through modern day hydraulics and fluid dynamics. For instance, the Venturi meter is not limited to hydraulics, but can be extended to gaseous systems as well (Soto-Ruiz et al., 2011). When the automobile was designed, flow rates needed to be considered for air intake within the carburetor. This led to the use of Venturi meters to regulate airflow and allow the correct mixture of air and fuel to be fed into the engine. Additionally, Venturi masks are used for controlled oxygen delivery. The mask uses the fundamentals of the Venturi effect and regulates a constant oxygen level to be delivered to a patient.

The uses of his innovations are seen to be endless, but Venturi was hesitant to accept his theories as resolute. As every thorough scientist would agree, the experiments he conducted still needed to be verified, which is explained in his quote: "The wisest philosophers have their doubts with regard to every abstract theory concerning the motion of fluids: and even the greatest geometers avow that those methods which have afforded them such surprising advances in the mechanics of solid bodies, do not afford any conclusions with regards to hydraulics, ..." From this, it shows that there are always uncertainties and lack of understanding in science and engineering, but fear of failure should never hold back ones curiosity and determination for understanding and innovation.

3 Jean Baptiste Perrin (1870-1942)

The Affirmation of Atoms

By Gabriela Caterini, Amber Klassen, Dylan Patterson, Josiah Inyeneobong, and Jesse Sop

"Mon cher, it would be difficult to propound a theory that is entirely false!" Jean Baptiste Perrin was a French physicist who was unafraid to challenge existing theories in theoretical physics, and who pushed the limits of what was known about atoms and molecules at the time. He received the Nobel Prize in Physics in 1926 for his groundbreaking work in verifying the existence of atoms and molecules (Berberan-Santos, 2001). Perrin's work with Brownian motion, which led him to such an achievement through his publication of *Les Atomes*, is noted to be one of the greatest books on physics written in the twentieth century. Perrin was a French nationalist who endured the hardships of both World War I (WWI) and World War II (WWII), and preserved the face of science against all odds. The opening quote to this essay illustrates his non-conformity to the prevailing schools of thought in physics during the time he lived. With this mentality, he could make numerous discoveries that changed the way people think about modern physics.

3.1 The Making of a Nobel Man

Perrin was born on September 30th, 1870 in the city of Lille, which is 220 km northeast of Paris and sits close to the Belgium border. His father was a retired infantry officer who perished in the Franco-Prussian War of 1870 (Raman, 1970). He grew up alongside his two sisters and his widowed mother. Perrin attended local schools during his early education including the Lycée Janson-de-Sailly in Paris. Perrin completed his undergraduate studies in 1894 in the sciences department at École Normale Supérieure in Paris where many other notable scientists graduated from (Raman, 1970). The École Normale Supérieure has the highest ratio of Nobel Prize laureates per alumnus of any institution worldwide, which there are a total of thirteen Nobel Prize laureates, including eight Nobel Prize winners in Physics (Clynes, 2016). Therefore, it is without a doubt that Perrin's undergraduate education served him well in his years leading up to his major scientific success. After graduation, Perrin was employed as a teaching assistant, and he conducted experiments on cathode rays (Raman, 1970). During this era, scientists were not in agreement about the characteristics of cathode rays. Perrin could prove during his days completing his doctorate degree that cathode rays are deflected in magnetic fields, so they must carry a negative charge (Hockey et al., 2007). This discovery began the start of several other discoveries that Perrin would make that would change the field of physics forever.

3.2 A New Worldview

Jean Perrin took science as a religion like many nineteenth century French men of science. A surviving pedestal located near Perrin's residence read: "Science, the only religion of the future" (Berberan-Santos, 2001). Perhaps, this explains the devotion Perrin could invoke into his scientific experiments. He was known to have great physical intuition to choose new and worthwhile topics of research, while putting forth new concepts and views to establish a general qualitative framework (Berberan-Santos, 2001). In this spirit, one of Perrin's most well noted scientific achievements was his confirmation of John Dalton's atomic theory on the particulate nature of matter, which had been made a full century earlier. This had been a highly debated but mainly theoretical topic until Perrin's experiments on Brownian motion confirmed the existence of atoms (Raman, 1970). Perrin suggested a model for the atom that bears a striking resemblance to the Bohr model of 1913. He spoke of a central charge surrounded by orbiting electrons somewhat like 'little planets' (Raman, 1970).

Perrin continued to experimentally prove theoretical research by spending many years continuing to learn about Brownian motion. In 1905, Albert Einstein released his famous analysis on Brownian motion, *Investigations on the Theory of Brownian Movement*. Perrin was able to prove Einstein's work in 1908, i.e. Einstein's prediction for the mean-square displacement of an ensemble of solute molecules in macroscopic time (Gillespie and Seitaridou, 2013). Perrin also aided Einstein in amending a mistake made in his thesis on Brownian motion in one of his approximations. Perrin's persistent work on the atoms as discussed above lead him to discover the discontinuous structure of matter which put an end to the struggle regarding the physical nature of molecules. Since he could sum up all the then known facts on molecules in his influential book *Les Atomes*, and because he confirmed the nature of atoms, he was awarded the 1926 Nobel Prize in Physics (Hockey et al., 2007).

Perrin also distinguished physical and chemical processes by the criterion of reversibility (Raman, 1970). It is believed that this is one of his more important contributions to science while being one of his most understated accomplishments. Since Perrin spent so much time looking at the world of theoretical physics through the eyes of an experimentalist driven by provable results, he could separate reactions into their two most general terms, physical or chemical, or reversible or irreversible. This was a fundamental building block that he and many other experimental scientists have elaborated on in their own work. Another important ideology that Perrin often repeated was that he felt that one of the functions of theoretical physics was to explain the complications of the visible in terms of the simplicity of the invisible (Raman, 1970). This was his way of trying to bring complicated topics into the lives of people who would ignore the subject. He applied the principles of the atomic level to how they would affect more mentally comprehensible objects. Perrin authored many papers such as *The Principles*, *Cathode Rays and X-rays*, and *Light and Chemical Reaction* (Raman, 1970). Alongside the Nobel Prize, he was awarded the Joule Prize of the Royal Society of London in 1896 and then became a member. He also won La Caze Prize of the French Academy of Sciences in 1914, and later became the President of the Academy (Raman, 1970).

3.3 Science, Love, and War

The accomplishments of Perrin in experimental physics as listed above have been documented in multiple sources of literature throughout the years. However, Perrin's extracurricular life was as inspiring as his scientific accreditations. Perrin's father died while fighting in the Franco-Prussian War. His father's death seemed to have instilled in him a great respect for the nation of France. At the time of the war, the Germans had succeeded in defeating the Austrians and other Northern states. The French however were a strong opposition to the totalitarian leadership the Germans had begun establishing. Under Napoleon III, the French opposition lost the war to the Germans and in turn had to surrender pieces of land to them (Wawro, 2005). Such were the times in which Jean Perrin was raised. Perrin grew to dislike the Germans as much as he was patriotic to his country. After serving a compulsory year of military service immediately after graduating, Perrin became immersed in the politics of France, just as he was immersed in atomic physics.

In 1897, Perrin was married to Henriette Duportal Michalovska, a cousin of Mme. Curie, who won a Nobel Prize in Physics and a Nobel Prize in Chemistry for discovering radioactive elements polonium and radium (Raman, 1970). Given that Perrin hypothesized that solar energy may be a result of thermonuclear reactions of hydrogen at the same time Mme. Curie made similar suggestions, it could be assumed that Perrin had a fruitful relationship with science within and outside of his family. Perrin contacted other prestigious scientists of his time. The collaborations were necessary because in the early twentieth century, the Germans had become well versed at employing science to the benefit of industrial advancements. The Germans therefore had more practical uses for science compared to the

French who had most scientists working independent of industry and state. Scientific research was therefore carried on with very limited financial resources, and Jean Perrin was still able to say that the allocation of money for research in the university was an irregularity which the government consented not to notice (Zeldin, 1993).

In 1914, France was plunged into WWI. Perrin enrolled as an officer in Engineer Corps in the Great War from 1914 to 1918. As a scientific advisor to the government, he was engaged in researches of practical importance during the war. During this period, he developed various acoustical devices, one of which was used in determining the direction of sounds from moving aircrafts and submarines (Raman, 1970). During this period of unrest, the Germans took over Perrin's hometown of Lille. Yet again, the French lost the war to the Germans, and it was left to men like Perrin to kick start the French economy. Perrin, being a socialist, proposed that collective ownership and distribution of wealth should replace the totalitarian movement of Europe at that time. He believed that science was not just an act of daily meticulous experimentations, but a way to makes progress and increase the possibilities of tomorrow. As President of French Academy of Science, he used his office to establish the Centre National de Recherché Scientifique (CNRS), which is currently the largest governmental research organization in France to this very day (Raman, 1970). He also assisted in establishing a science museum called Le palais de Decouverte. The museum currently holds works from mathematics, physics, and astronomy from centuries ago (Hockey et al., 2007). It is well documented that Perrin was so enthusiastic about the freedom of science that he would gather young students in his laboratory and host parties that allowed for long discussions on different topics (Raman, 1970).

In 1940, at the outbreak of WWII, Perrin was forced to flee France to New York. In New York, Perrin did not abandon his enthusiasm for science. He assisted in establishing the French University of New York. Two years after his arrival in New York, Perrin died at the age of 71 (Raman, 1970). Perhaps, having fought the wars in his own way, it was time for Perrin to be laid to rest.

In conclusion, Jean Baptiste Perrin was an instrumental figure in settling long lasting disputes in the world of theoretical physics. He successfully proved the atomic nature of matter through meticulous experimentations, which were groundbreaking in those days. Beyond science, Jean Perrin showed exceptional interest in the practical nature of the world. He recognized that science is not just an independent venture, but rather one that needs collaboration from an enthusiastic state government and young students willing to embrace that what is inaccessible today, may be accessible tomorrow. Even in times of war and strife, Perrin shows us that there is a place for tranquility and discipline not just in science but in every walk of life.

4 Edgar Buckingham (1867-1940)

Life and Its Struggles

By Liam Brand, Blake Aram, Terra MacMillan, and Andrew McClelland

4.1 Life and Achievements

Edgar Buckingham was born in Philadelphia, PA, on July 8^{th}, 1867. He graduated with a bachelor's degree from Harvard University, in 1887. After graduating, Buckingham then worked for several years as a graduate student assistant within the physics department at Harvard University. He then moved onto subsequent graduate work at the University of Strasbourg and the University of Leipzig, in France and Germany, respectively. At the University of Leipzig, Buckingham studied under the chemist Wilhelm Ostwald, who was the recipient of the Nobel Prize in 1909 (Nimmo and Landa, 2005). In 1893, Buckingham completed his Ph.D. from the University of Leipzig.

The same year Buckingham completed his Ph.D., he began his teaching career at Bryn Mawr College. During the time period 1897-1899, he taught physical chemistry as well as physics at the college (Nimmo and Landa, 2005). Buckingham also finished writing his first textbook in the area of thermodynamics during this time (Buckingham, 1900). In the summer of 1899, Buckingham left Bryn Mawr College to pursue future endeavours.

At this time, Buckingham moved back to the United States where he was approached by Harvard president Charles William Eliot. From the meeting, he began a seven-month work term at a mining camp in Morenci, AZ, in conjunction with the American Institute of Mining Engineers (Nimmo and Landa, 2005). During the period when Buckingham left Bryn Mawr and completed working in Morenci, he courted his soon-to-be wife Elizabeth Holstein, whom he met at his time at Bryn Mawr College. The couple were married in Texas in 1901 and he subsequently resumed his teaching career at the University of Wisconsin.

After only a year of working at the University of Wisconsin, Buckingham left his position to work at the United States Department of Agriculture (USDA) Bureau of Soils (BOS). Buckingham worked at the BOS from 1902 to 1906, where he developed his knowledge of the dynamics of gas and water in soils (Nimmo and Landa, 2005). The research he accumulated during this time was described in the reports, *Contributions to Our Knowledge of the Aeration of Soils* and *Studies on the Movement of Soil Moisture* (Buckingham, 1904, 1907). Also during this time, Edgar and Elizabeth had a daughter, Katherine Buckingham, born in 1902 and a son, Stephen Buckingham, born in 1905.

After leaving the BOS in 1906, Buckingham went on to work for the National Bureau of Standards (NBS) until his retirement in 1937. During his time at the NBS, he was the first researcher to receive the prize Independent Status, which meant he was essentially free of all administrative duties (Nimmo and Landa, 2005). He also worked in the area of helium production, specifically for the military, and as technical oversight of NBS support of rocketry studies by Robert Goddard (Nimmo and Landa, 2005).

Three years after his retirement from the NBS, Edgar Buckingham passed away on April, 29, 1940. He was described as a man of strong personality, outspoken, and uncompromisingly truthful. He left behind a legacy in which his research is still used today.

4.2 Bureau of Soils Dispute

Although Buckingham enjoyed what many would consider an illustrious career in the scientific field, it did not go without its share of conflict and doubt. He concluded a series of experiments with regard to soil moisture transport on July 2^{nd}, 1906 and subsequently published his famous paper, *Studies on the Movement of Soil Moisture* in Bulletin 38 of the U.S. Department of Agriculture (USDA) Bureau of Soils (BOS) in the year 1907 (Narasimhan, 2005). Between the completion of his experiments and the publication of the paper, there was an internal dispute at the BOS between Buckingham and his supervisor at the time, Frank Kenneth Cameron (Nimmo and Landa, 2005). Cameron was a successful scientist in his own right, receiving his Ph.D. in chemistry in 1904 from John Hopkins University and heading the soil chemistry laboratory from 1899 to 1915 (Nimmo and Landa, 2005). The conflict arose when Cameron brought up the argument through a series of letters that a contradiction existed between Buckingham's theory and fundamental laws of thermodynamics. Cameron's reasoning started with a hypothetical experiment in which an apparatus with two cylinders of different height, both having their bottoms submerged and open, while their tops were not submerged and closed. The predicted constants from Buckingham's theory would create a system in which vapor would circulate from the smaller cylinder to the larger one and then condensate and fall back into the water, only to be evaporated once again in the small cylinder. The important point being that it is a perpetual system in which thermal energy is spontaneously being transformed into mechanical work and therefore contradicted the second law of thermodynamics, stating that total entropy can never decrease over time for a system in which neither energy nor matter can enter nor leave.

Buckingham replied to Cameron in a non-formal letter that essentially told him that he did not see any problem with his theory. Cameron's mistake was that he assumed uniform atmospheric conditions over the entire height of both cylinders. In reality, water vapor pressure and water content would vary throughout the column and therefore create a system favouring one process in the column (evaporation for example) and hence forth, the system would not be perpetual (Nimmo and Landa, 2005). While it was obvious that Cameron was very hesitant and anxious in his writing to Buckingham, he did not take the matter any farther as Buckingham was known to have a great grasp on fundamental principles of physics (Nimmo and Landa, 2005). The fact that Buckingham had the confidence to contradict and oppose his supervisor's point of view without much thought can be taken as arrogance, but it also shows how great of a scientist Buckingham was. In a later letter Buckingham showed that he did appreciate the thought Cameron put in to his work and even went as far as wishing him an enjoyable vacation (Nimmo and Landa, 2005).

The dispute however continued with Milton Whitney, director of the BOS, in November of the same year when Buckingham wrote a concluding discussion that he intended to be published as the final portion of Bulletin 38 (Nimmo and Landa, 2005). The discussion presented Buckingham's vision of future research that would be conducted to bring his theoretical framework to a practical fruition. Whitney however, deemed Buckingham's conclusion "unwise [and stated that] it would weaken rather than strengthen the paper". Buckingham did not take too kindly to this, expressing how he thought it was a mistake to omit his concluding remarks. In the end, the paragraphs written by Buckingham were not included in Bulletin 38 suggesting that Whitney failed to see the importance of Buckingham's work (Nimmo and Landa, 2005).

4.3 Buckingham's Pi Theorem

Among Buckingham's most notable achievements is his famous Buckingham's Pi theorem for dimensional analysis. Explained in his 1914 publication on physically similar systems, and illustrating the use of dimensional equations, the theorem provides a method for determining sets of dimensionless parameters from available variables that are related in a system by an equation even if the form of the equation is unknown (Buckingham, 1914). Buckingham's theorem is a formalization of Lord Rayleigh's method of dimensional analysis that was developed in 1877. However, it is now known that in 1892, a Frenchman A. Vaschy, and in 1911, a Russian, D. Riabouchinsky, had also independently published papers equivalent to Buckingham's Pi theorem, although Buckingham is still credited with the publication of the idea (White, 2003).

Buckingham's Pi theorem has major applications in the engineering field specifically fluid and soil mechanics, but its use is not limited to engineering as it has been seen to also have applications in the fields of meteorology, astrophysics, economics, chemistry, medication, social sciences, biomedical sciences, herbology and many others (White, 2003). Many aspects of Buckingham's Pi Theorem were incorporated into similitude analysis, which allows for extrapolation from model scale to full scale. A model is said to have similitude with the full scale when geometric similarity, kinematic similarity, and dynamic similarity have been achieved (White, 2003). The application of similitude analysis is considered essential to the engineering field, specifically fluid and soil mechanics.

4.4 Significance in Modern Time

Edgar Buckingham was undoubtedly a genius, who often thought ahead of his time in the scientific world. He possessed interests in physics, soil mechanisms, and dimensionless analysis, devoting his life to each, having 'revolutionized' a field by the time he moved to the next (Narasimhan, 2005). As mentioned earlier, his work on dimensionless analysis and the development of the Buckingham Pi Theorem is still implemented in major fields of science to this day. Utilizing his theorem has enabled scientists and engineers to mathematically model complex systems.

Buckingham's work is also recognized today through the analysis and study of modern soil mechanics and hydrology. Although some believe Buckingham's work on capillary moisture movement and unsaturated flow is identical to that of Henry Darcy, others argue that Buckingham's work is unparalleled (Narasimhan, 2005). This is a result of Buckingham having developed a dynamical theory, producing the equation commonly known as Darcy's law, whereas Darcy used mathematical analogies based on the works of previous scientists (Narasimhan, 2005). Regardless of methodology, Buckingham's work helped develop one of the most common equations still used today in the field.

It could be argued that there are two types of scientists who emerge throughout history: the analytical scientist, who develops theories and models based on the works of previous intelligence, and the applied scientist, determined to test theories and generate concrete conclusions. Edgar Buckingham, like many others, is both those scientists. His life accomplishments have derived from the study of past scientists, along with his ability to conceptualize problems from different perspectives to quantify viable solutions which are still used today.

5 Lorenzo Romano Amedeo Carlo Avogadro (1776-1856)

Bold Enough to Diverge

By Jane Pirie, Mostafa Elkurdy, Andrea Cline, Andi Kokojka, and Julian Kuntz

Our family history and legacy can often have a dramatic influence on our own career paths and life choices. It is not uncommon for people to follow in their family's footsteps because that is usually the path of least resistance. However, there are individuals who choose to diverge from the norm and this choice of deviance can sometimes have a huge societal impact. Lorenzo Romano Amedeo Carlo Avogadro is one of those special individuals.

5.1 Childhood and Early Years

Lorenzo Romano Amedeo Carlo Avogadro was born on August 9^{th} in 1776 into an illustrious family of lawyers (Burns et al., 2008). Lorenzo was born and raised in the town of Turin, which was the largest town in the Piedmont region located in Northern Italy (Burns et al., 2008). His family was aristocratic, noble and continuously provided legal service to the church and state. Lorenzo's father, Filippo Avogadro, was an acclaimed lawyer and senator in Turin. Filippo worked to reorganize the Piedmont government and was charged under the Napoleonic rule of 1799. His mother was a noblewoman named Anna Vercellone of Biella. Growing up in a dignified family of lawyers, Avogadro was bred to follow his family's legacy in law and politics. His family's history in government and law pushed Lorenzo to also pursue a career in these fields. However, Lorenzo's eventual decision to deviate from his political lineage triggered fundamental discoveries in the world of science. The field of chemistry would be radically different without Lorenzo's decision to pursue a career in science.

5.2 Education and Adulthood

Lorenzo was an intelligent individual that studied at Jurisprudence where, in 1796, he received his doctorate in ecclesiastical law (Burns et al., 2008). He then began to practice law after receiving his doctorate. Lorenzo gradually lost interest in the study of law as his preferences shifted toward the sciences. As his preferences shifted, he began to study sciences, which were largely self-guided and focused on mathematics and physics (Burns et al., 2008). While he studied, he had few personal contacts with expert European scientist; the isolation was thought to be impacted by culture more than geography (Rocke, 1984). Through Lorenzo's study of science, he began researching electricity and in 1804 became a member of the Academy of Sciences of Turin. During Lorenzo's study in science he was practicing law, but in 1809 he left his successful legal practice to become a professor at the Royal College of Vercelli in natural philosophy (Burns et al., 2008). During his time in natural philosophy, he made one of the most significant contributions to science, the hypothesis that equal volumes of all gases at the same temperature and pressure contain the same number of molecules, which was published in 1811 (Burns et al., 2008). This contribution to science at the time was not acknowledged partly because of the contradiction to prior opinions in the field (Burns et al., 2008). It was thought that if the scientific community saw the importance of Lorenzo's work, in the way that scientists view his theories today, he would have made the choice to devote much more significant portion of his time and energy to theories of chemistry, atomic weight, and chemical structure (Hinshelwood and Pauling, 1956).

In 1819, Lorenzo became a full member of the Academy of Sciences of Turin (Burns et al., 2008). Lorenzo occupied this position until he accepted the first chair in mathematical physics at the University of Turin in 1821 (Burns et al., 2008). In 1822 the chair was taken away from Lorenzo due to political reasons. He was reappointed in 1834 at the University of Turin. He occupied the chair from 1834 until he retired in 1850 (Burns et al., 2008). In the last years of Lorenzo's career, he focused his research on atomic volumes (Burns et al., 2008). From 1820 to 1842, save for a few exceptions, Lorenzo was only published in local Italian journals; this was thought to be related to his contemporaries demonstrating little interest in his work (Rocke, 1984). Lorenzo was thought to be isolated in his field of research and perhaps was born too early for his contributions to be acknowledged during his lifetime toward the evolution of science (Burns et al., 2008).

5.3 Theoretical Findings

While Avogadro was a Professor of Physics at the University of Turin, he studied several different subjects (Williams, 2016). Physics during this time period focused on the nature of gases. Celebrated physicists, such as Joeseph Louis Gay-Lussac, believed that when gases reacted the volumes of the products were produced at a certain ratio with the reactants (Williams, 2016). Avogadro expanded on this theory with what is now known as Avogadro's theory.

Avogadro's theory is a principle that was established in 1811 that states; "equal volumes of gases at the same temperature and pressure contain the same number of molecules regardless of their chemical nature and physical properties". When Avogadro released his publication theorizing this relationship, it received little reaction. This may be due to his lack of effort to share his findings with the French and German scientists, but also the apparent exceptions to the law, which were later resolved with the discovery of dissociation (Williams, 2016).

His number is now known as the Avogadro's number (N_A) equal to 6.022×10^{23} although it was not calculated until much later in the latter half of the 19^{th} century (Jensen, 2007). It is the number of molecules of any gas present in a volume of 22.41L, and is the same if you take a light gas such as hydrogen or a heavy gas such as carbon dioxide, and compare the two. The law can be stated mathematically using the equation $V/n = k$, where V is the volume of the gas, n is the amount of substance of the gas, and k is a proportionality constant.

The most important consequence of Avogadro's law is that the ideal gas constant has the same value for all gases. This means that, no matter the size or mass of the gas molecule, the constant C remains the same, i.e. $pV/(Tn) = C$, where p is the pressure of the gas and T is the temperature of the gas in Kelvin temperature scale.

One mole of an ideal gas occupies 22.41L at standard pressure and temperature. This volume is often referred to as the molar volume of an ideal gas. Real gases may deviate from this value since their properties and conditions will be different.

Avogadro's number in chemical calculations is now considered to be the number of atoms present in twelve grams of the carbon-12 isotope (one mole of carbon-12) and can be applied to any type of chemical entity.

5.4 Theoretical Acceptance

Many factors relating to the time and place that Avogadro's theories were published did not work in his favour. The renaissance was a major cultural movement in Europe that began in Italy and went on from 1300s to 1700s. This time period brought up many revolutionary Italian names in science such as Leonardo da Vinci and Galileo, who added a sense of distinction to the name of Italian science. However, as this movement spread across Europe later on, and as it came to an end, Italian scientists were no longer viewed in the same regard. Unfortunately, for Avogadro, being born in Italy decades after this time of great societal advancement and discoveries in science, may have been a major factor in his work being disregarded and not accepted until decades after his death.

Furthermore, the basis behind Avogadro's theory itself caused his work to be rejected for decades, as it contradicted some of the leaders in science at the time. John Dalton was (and still is) a well-respected scientist at the time due to his discoveries relating to atoms and elemental chemistry. However, at the time, scientists such as Dalton believed atoms were held together by electric forces. This meant that similar atoms could not attract and be held together, as oxygen or hydrogen molecules are. Avogadro's theory contradicted this and made a distinction between atoms and molecules, which Dalton had rejected.

Avogadro's brilliant work was not recognized until 1860, where at the first international conference on chemistry in Karlsruhe, Germany, Stanislao Cannizaro explained Avogadro's ideas and their ability to address much of the confusion in the world of chemistry at the time. Once his work was accepted, it allowed for an enormous advancement in the field of chemistry. Just nine years after the acceptance of Avogadro's ideas Dmitri Mendeleev developed the first periodic table with the help of Avogadro's findings. Sadly, in 1856, Avogadro passed away a mere four years before his theory was accepted and so he never saw the impact his research had on the world.

Lorenzo Romano Amedeo Carlo Avogadro was born into the highest level of society, and although he did not ultimately practice law as generations before him, he maintained several public positions while developing his scientific theories. While Avogadro was not recognized for his input into science during his lifetime, he is regarded as one of the founders of atomic-molecular chemistry today based on the advancements in the scientific community after the acceptance of his theory. His major theories, now known as Avogadro's law and number, were an enormous advancement ignored by the scientific community at the time. Years after his death, his theory is still being used; for this, we are glad he chose not to follow the path of least resistance.

6 Jean Baptiste Joseph Fourier (1768-1830)

The Mathematical Poem

By Jake Lemke, Bryan Meyers, Raquel Castro, Shiying Lin, and Melanie Kabelin

British mathematical physicist, William Thomson Kelvin, once praised, "Fourier's Theorem is not only one of the most beautiful results of modern analysis, but it is said to furnish an indispensable instrument in the treatment of nearly every recondite question in modern physics ... Fourier is a mathematical poem" (Arago, 1857).

6.1 Journey Behind the Epic Life

On March 21, 1768, a boy was born in Auxerre, France, and thus began the journey of a great and epic life. Jean Baptiste Joseph Fourier was orphaned by the age of ten, and was placed in the hands of the Bishop of Auxerre to pursue Latin and French (Kautz, 2011). As were his heart's desires, his passion for mathematics soon took over, and his reputation for early brilliance gifted him the opportunity to study amongst children of nobility at the École Royale Militaire d'Auxerre. The school was run by Benedictine Monks who raised and educated Fourier.

Within a year, thirteen-year-old Fourier completed all six volumes of Etienne Bézout's Cours de Mathématiques (Debnath, 2012). His tenure at École Royale Militaire d'Auxerre influenced him greatly as it introduced him to his true passion, which was mathematics.

As Fourier was growing up, he started to wonder if he should follow a religious career or continue with mathematics. At the age of nineteen, he travelled to St. Benoit-sur-Loire to enter the Benedictine abbey as a novice (Kautz, 2011). Two years later, in 1789, Fourier followed his calling and abandoned his path to the priesthood. He submitted his first original contribution to the industry, a paper on algebraic equations, to the Royal Academy of Science (Blyth and Robert, 2002). As if fate had written his story, Fourier was thrown back into life as a mathematician as he took a job opportunity at his childhood school, École Royale Militaire d'Auxerre (Blyth and Robert, 2002).

During Fourier's time at Auxerre, he became increasingly interested in the ideals of the French Revolution and joined the Revolutionary Committee in 1793 (Kautz, 2011). Joseph Fourier had found a passion for fighting against the Reign of Terror, and was arrested in 1794 for defending a certain political faction in Orléans (Blyth and Robert, 2002). Fourier was released upon the execution of Maximilien Robespierre, creator of the Terror, and began working as a mathematician once again (Kautz, 2011). After a brief period at the École Normale Supérieure in Paris, taught by Joseph-Louis Lagrange, Pierre-Simon Laplace, and Gaspard Monge, Fourier was offered a position to teach Mathematics at the École Polytechnique (Kautz, 2011). Only three years after he began this position, Fourier exceeded Lagrange by becoming the new chair of analysis and mechanics at this school.

6.2 Truth Behind the Theories

A large part of Fournier's significant contributions to the realm of science came later in his life. He joined Napoleon Bonaparte's Egyptian expeditions after four years at the École Polytechnique as a scientific advisor from 1798 to 1815. He joined this expedition based on the recommendations of the highly regarded mathematicians Monge and Berthollet (Hawking, 2007). From his role in the development of Egyptology and archeological work, Fourier developed a passion for the nature and laws that govern the natural world. As stated by physicist Richard Kautz, Fourier "proved capable in both realms, participating in archaeological explorations, collating the scientific discoveries, and successfully concluding the many delicate negotiations required to maintain the expedition's tenuous military position" (Kautz, 2011). In 1801, Fourier returned to his position as Professor of Analysis at the École Polytechnique. One year after, he was appointed Prefect of Isére in Grenoble by Napoleon (Debnath, 2012). Being loyal to the Emperor of France, he dedicated himself to the job and excelled although his thoughts were always with mathematics.

Napoleon revered Fourier and rejected pleas from fellow French scholars and colleagues such as Laplace and Monge to rid him of governmental duties. Despite these circumstances, Fourier found the time and energy to continue his academic work on natural laws, focusing on the theory of heat conduction based on the use of his trigonometric series, the later denounced Fourier series. His first work, *On the Propagation of Heat in Solid Bodies*, was submitted to the Academy of Sciences in Paris for a research prize in 1807. The work was reviewed by a committee of great scientific minds including Laplace, Monge, Lagrange, Adrien-Marie Legendre, and Sylvestre-Francois Lacroix (Debnath, 2012).

There was a lot of controversy that followed the review of this paper. Lagrange criticized the quality of his use of trigonometric expansion. The work was also criticized for the derivation of heat equations (Debnath, 2012). As a result, the committee rejected Fourier for the prize but saw the underlying quality of his theory and encouraged Fourier to continue his work. Fourier's mathematical theories were also harshly criticized by Siméon-Denis Poisson and Jean-Baptiste Biot but were silenced from his response to the criticism in *Historical Précis* and through letters to Laplace on certain analytical expressions in relation to the theory of heat.

Constantly trying to improve on his academic abilities, Fourier resubmitted his work in 1811 including the cooling of infinite solids, radiant and terrestrial heat, and experimental observations proving his theory. This awarded him the Grand Prize in 1812, however the work came short of being published in the Academy's Mémoires due to Lagrange's continued objection to the trigonometrical series (Debnath, 2012). The mathematician was elected member of the Académie des Sciences, despite objections of the relenting King Louis XVIII from Fourier's ties with Napoleon. Later, in 1822, he was offered the directorship of the Bureau of Statistics (BOS), which he remained at until his death in 1830 (Hawking, 2007).

Fourier continued to revise his research for publication at the Academy. Later that year, he produced his final masterpiece, *The Analytical Theory of Heat*, based on the laws of cooling derived by Isaac Newton where heat flow between particles is controlled by the difference in temperature (Hawking, 2007). This theory proved of great importance to the field of mathematics through the development and use of the Fourier series first introduced by Daniel Bernoulli for analysis of vibrating strings.

Fourier was able to solve for the coefficients in the series and contribute to a theory which would have widespread and long-lasting applications. These future applications include linear water waves analysis by Augustin-Louis Cauchy and Poisson, solving vibrating strings (initially worked on by Bernoulli, Lagrange, Leonhard Euler, and Jean le Rond D'Alembert), and James Clerk Maxwell's Electromagnetic Theory and Kinetic Theory of Gases (Debnath, 2012).

As a mathematician, Fourier cared about the stringency particle in particle problems as much as Augustin-Louis Cauchy and Niels Henrik Abel. However, he was not able to interpret the critical meaning of the limit theory. The talent of Fourier shines in analysis mechanics. At that time, the mystery of calculus had not been revealed, so the main functions appearing in analytical machines were often non-linear, and the solutions were solved using approximation. Fourier created and explained a coherent method for solving the partial differential equation. In Fourier's mind, all mathematical statements should have their own physical meaning in two aspects: physical motion and the ability to be measured. In that way, he would always be able to compare his mathematical solutions to real-life experimental results. Based on Fourier's draft physical model developed in his early years, he began to include physical constants into his theory of heat in 1807. With his attention to the true meaning of physics, Fourier discovered the potential in experimenting and comprehending, which tested the correlation between groups of physical constants for index decomposition.

6.3 Foundations for the Greenhouse Effect

Joseph once stated, "The question of global temperatures, one of the most important and most difficult in all natural philosophy, is composed of rather diverse elements which should be considered under one general viewpoint" (Ramanathan, 1988). Among his many accomplishments and works, Fourier was the first scientist of his time to propose an explanation for what is modernly known as the Greenhouse Effect. In his many articles published between 1824 and 1827, Fourier discussed how a body the size of Earth, being as far away as it is from a source of heat such as the Sun, should be much colder than the Earth actually is. From this, Fourier determined that there must be an alternative reason for the Earth's warm temperatures.

In trying to determine how the Earth can hold in heat, Fourier discussed a variety of potential explanations. In his published article from 1824, he discussed that the Earth is heated by three mechanisms. These include solar radiation that is distributed over Earth, heat that is transferred between planets and originates from countless stars, and heat from the interior of the Earth, which is still being released from the Earth's formation (Fleming, 1999).

The conclusion that Fourier arrived at was that the Earth's atmosphere must be able to absorb or retain heat from solar radiation, instead of it all being reflected off the planet's surface. His explanation for this was that the heating of the atmosphere surrounding the Earth has a similar action to that of a heliothermometer. These devices were used in the 1760s and were composed of a wooden box lined with black cork, with a small window on the side (Fleming, 1999). Sunlight entered the box through the window, which had three separated layers of glass.

The design of the box allowed the Sun's rays to enter the box, with the heat of the rays being amplified by the glass (Fleming, 1999). In this way, Fourier concluded that the Earth's atmosphere acts in a similar way to the clear panes of glass of the heliothermometer. The atmosphere's ability to trap heat and warm the Earth was later coined as the 'Greenhouse Effect' due to its similarity of how the clear glass roof of a greenhouse traps heat inside (Debnath, 2012).

6.4 The End or the Beginning?

Despite Fourier's wisdom and intelligence in mathematics and science, he was constantly suffering from a series of health issues throughout his life. Upon his return from Egypt and Grenoble, Fourier experienced attacks from heart aneurisms (Arago, 1857). After his final publication of *The Analytical Theory of Heat*, Fourier also suffered from chronic rheumatism. He might have struggled from malaria as well, which may have been caught during his time in Egypt (Arago, 1857). Fourier's obsession in the theory of heat led to his success in the academic world. However, with his critical health conditions, Fourier refused to treat the threatening symptoms unless it was only with the aid of patience and high temperatures (Hawking, 2007).

On May 16, 1830, one of the brightest minds of the academic world, Jean Baptiste Joseph Fourier, had ceased to live at the age of 62 due to nervous angina and critical heart issues (Arago, 1857). His work with trigonometric series, differential equations, warming of the Earth's atmosphere, and so much more will be used and appreciated every day, and will live on as contributions from a great and influential mathematician.

7 Ludwig Prandtl (1875-1953)

The Father of Modern Aerodynamics

By Bridget Thai, James Stock, Jason Dorssers, Hanna Ivankovic, and Elizabeth Blissett

7.1 The Making of the Man - Early Life and Scientific Influences

Ludwig Prandtl was born on February 4^{th}, 1875 in Freising, Bavaria. He was born as son of Alexander Prandtl, a professor of surveying and engineering at the Agricultural Central School in Weihenstephan. Prandtl's father was a great lover of nature, filling his childhood environment with lessons to observe natural phenomena and reflect on them. Being close to his father, Prandtl developed not only an interest in physics, machinery, and instruments, but also a remarkable ability to go straight to the heart of a physical problem (Anderson, 2005).

In 1894 Prandtl started his studies in mechanical engineering at the Technishe Hochschule in Munich where he met his principal teacher, future doctoral advisor, and future father-in-law, August Foppl. Up until he graduated from the University of Munich on January 29^{th}, 1900 with a Ph.D., Prandtl showed no interest in fluid mechanics; however, he would soon have his first significant encounter with the man who would shape his legacy.

The famous mathematician Felix Klein had taken an interest in Prandtl at the turn of the century and would come to play an important role in his future. See, Felix Klein had a vision; one where practical engineers and noble thinkers could come together at universities—something unheard of back in the day. He acted on this vision at his Göttingen University, which implemented chairs for technical science as well as pure sciences. Within this vision, he saw Prandtl, who was a full professor in Hanover at the time.

Although it took four years, in 1904, Klein managed to convince Prandtl to give up his full professor status to join Göttingen as an associate professor, much to the dismay of his doctoral advisor Foppl. But his associate status would not last for long. Prandtl made his way up to full professor at Göttingen and was also the chair for mechanics, of which only one was held in all of Germany for almost half a century. It was here that Prandtl would transform Göttingen to the Centre of Aerodynamic Research in Germany. Later in life, when asked about Klein, Prandtl would respond, "He was my fate" (Oswatitsch and Wieghardt, 1987).

7.2 Harmonious Theory and Practice

In the early 1900s, Ludwig Prandtl combined two diverging fields within fluid mechanics, one of intense theory and another of precise technical specialty. This was commonplace in Germany at the time due to the differences between 'technical' and 'regular' universities. At Göttigen university, Prandtl would eventually become a head professor teaching mostly about simple mechanics and physical sciences. However, he would use these facilities to conduct research within the field of fluid separation, his true passion. After months of experimentation, Prandtl identified a localized friction within a very thin 'boundary layer.' During his presentation at the Heidelberg Congress he introduced his famous boundary layer theorem for the first time. Prandtl describes his findings as such, "the physical processes in the boundary layer between the fluid and the solid body is addressed in a sufficient manner if one assumes that the fluid does not slip at the walls, so that the velocity there is zero or equal to the velocity of the solid body" (Eckert, 2006). During the demonstration, over half of the focus was purely on visualization of the concepts presented. At the time, this was irregular for a presentation in front of such highly regarded mathematicians. An engineer at heart, Prandtl refused to allow mathematics to overshadow his treasured practical discovery.

Before the dawn of World War I (WWI), the study of aerodynamics focused on balloon and airship flight. Previously, testing on these models incorporated a 'sucking tube,' a device that ventilates air by way of a fan. During his early boundary layer experiments, Prandtl used a water canal consisting of two tiers. The tiers were separated by a wall, and water was fed from the top into the bottom tier via a paddle wheel. As the water flowed back into the first tier, Prandtl noticed less rippling around the thin edge of the separation wall. He proposed a design for an advanced wind tunnel that circulated airflow much like his water trough the apparatus. This 'windkanal' aided in the design of the first airships created in Germany with minimal air resistance and drag. Eventually, Prandtl would move onto more advanced theorems in the field of aerodynamics.

Prandtl's contributions to aerodynamics extend well beyond the discovery of the boundary layer theory. Many of his early wind tunnel experiments centred around advancing the understanding of airflow around wings. It took many years of experimentation and refinement from other noteworthy scientists including Wieselberger before Airfoil Theory became a comprehensive theory. Airfoil theory was effective in describing the vortices created by airflow around a wing and how these upwardly swirling vortices contribute to lift and drag on an airplane in motion. Wieselberger was able to make interesting connections with Prandtl's airfoil theory and the V-shaped flight patterns of migrating birds. The vortices described in airfoil theory are created by the wing tips of in-flight birds which results in added lift for birds immediately to the left and right of the leading bird, generating increased lift for every bird thereafter and thus the most efficient flight (Eckert, 2006). Airfoil theory was, and still is, one of the most important in the development of airplane wings, with early forms of airfoil theory were also used to describe the advantages and disadvantages of using biplanes versus monoplanes for different flight patterns, information that would become very important to the German army during the global conflicts to come.

7.3 The Fight for Science: WWI and WWII

Due to the inherent militaristic applications of Prandtl's research, many of his discoveries were employed when developing aviation technology during WWI. Airfoil theory was finally published in 1918, right at the end of WWI and it is often speculated that the publication of this theory was delayed to keep it secret for the German army. "In the First World War, the airplane became a weapon" and the perfection of this weapon was incredibly important (Eckert, 2006). The need for research in the fields of aviation and aerodynamics rose dramatically in 1914 and Prandtl was able to secure military funding to build an institution for the research of hydrodynamics and aerodynamics. The facility became known as Modellversuchsanstalt für Aerodynamik, which was later renamed to Aerodynamische Versuchsantalt after WWI. It was here where Prandtl developed many of his theories including his greatest contribution to aerodynamics: the Boundary Layer Theory. While Prandtl was able to maintain a civil and lucrative relationship with the German army throughout WWI, the same cannot be said for Prandtl and the Nazi regime of WWII.

Courageous and passionate are two words that can be used to describe Ludwig Prandtl. On multiple occasions, Prandtl took a stand against the Nazi Party in order to preserve the integrity of science.

On September 29, 1933, Prandtl received an order to dismiss Jewish employees of the university (Vogel-Prandtl, 2014). Even after receiving the threat of being sent to a concentration camp, Prandtl still continued to fight, stating in a letter to the president of the institute, Max Planck, in 1934, that "The reason for my not letting the matter rest, as you suggest, is simply as follows: [...] I myself have the liveliest interest in correcting the picture of conditions in our Institute that has arisen from the discussions" (Vogel-Prandtl, 2014).

Under Nazi rule, there was a movement to abolish modern physics, such as Einstein's theory of relativity, and to instead focus on Arisch Physik (Aryan Physics) (Vogel-Prandtl, 2014). This was enraging to Prandtl, he wrote a letter to SS Reichsführer Heinrich Himmler in 1938, in which he stated:

"There are indeed, among the 'non-arisch' people, scientists of a class that must be regarded as the foremost of the best. [...] Science simply faces the fact that laws have been discovered that in turn have led to further discoveries which cannot be ignored without dismantling the structure on which they were built" (Vogel-Prandtl, 2014).

The fight for science continued, and in 1939, Prandtl was chosen to consult on the Munich Chair for Theoretical Physics. It was then that he made the statement that appointing an Aryan physicist would be "[...] an act of sabotage against further technological development" (Vogel-Prandtl, 2014). It is clear that Prandtl was willing to stand up for the future of science; he was not only a brilliant man; he was extremely courageous as well.

7.4 The Prandtl Legacy

One of Prandtl's focuses post WWII was the new beginning of the Göttingen University and to ensure his status in support of denazification. Staying true to himself as an engineer, his main concern was for the denazification of the univerisities, stating:

"The universities must support the principle that all those young people who are valuable—because of their human as well as their academic qualities—as researchers or teachers, who were not activists, can now be received graciously back again and not come to harm as a result of the fact that, in the last few years, they had no alternative but to follow the path of the party, which was completely merged with the state. The whole new generation of the university teaching body depends on this decision" (Vogel-Prandtl, 2014).

His work then continued, establishing a colossal footprint on fluid dynamics and engineering. His legacy lives on in numerous accounts having his advancements in the applications of fluids and aerodynamics still used today. Notably, the Prandtl number and his calculations in reference to cambered airfoils from his work in WWI; all supersonic wind-tunnel nozzles and rocket-engine nozzle designs can be attributed to the work of Prandtl and his student Theodor Meyer. Compliment to Prandtl is demonstrated by the National Aeronautics and Space Administration (NASA) paying tribute to Prandtl and his work through the Prandtl-M: Preliminary Research Aerodynamic Design to Land on Mars) research aircraft, an acronym in honour of his name.

Prandtl's life sadly came to an end after suffering a stroke in the year of 1952, and passed away on the 15^{th} of August 1953. His positive influence on his students and fellow scientists was uncanny. "[...] The Ludwig Prandtl Ring has been awarded to many deserving researchers in the field of aerodynamics who once worked alongside him as his students. These are scientists of a special class, who advanced science and gave it a new impulse" (Vogel-Prandtl, 2014).

It can easily be stated that face of fluid dynamics and aerodynamic engineering would not be the same without the work of Ludwig Prandtl, a courageous leader in science, a pioneer of aerodynamics, and a symbol of freedom and intellect.

8 Geoffrey Ingram Taylor (1886-1975)

Redefining Fluid Dynamics

By Matthew Butts, Denis Clement, Cheng Chen, and Danielle Nyarko

8.1 Introduction

The power of science and mathematics is endless. Every day, brilliant minds across the globe strive for new and refined discoveries and explanations in the universe around us. Whether for good or evil, the progress of science, especially in the last 150 years, continues to be truly astonishing. Some of these discoveries, including the world wide web, the atomic bomb, and the internal combustion engine, are arguably among the best and worst creations for humanity, by humanity. Sir Geoffrey Ingram Taylor, a British physicist and mathematician, has made major contributions to theories and discoveries of a similar nature (Batchelor, 1976). For example, Taylor worked on solving implosion instability problems during the development of the plutonium bomb used at Nagasaki on the 9^{th} of August 1945. Though he is considered one of the most successful and well-respected scientists of the 20^{th} century, Taylor used his intellect to improve on other aspects of science and engineering. For example, Taylor was driven to explore some of the fundamentals of his simpler interests and hobbies including the design of a new type of anchor inspired by his love for sailing and aeronautics. In 1913, Taylor perpetuated his interest in aeronautics by serving as a meteorologist on the Scotia, the first vessel of the International Ice Patrol after the sinking of the Titanic (Batchelor, 1976). Sir Geoffrey Ingram Taylor had a variety of fields of research including dispersion and diffusion in turbulent flows, plastic strain and deformation in materials, stability of viscous liquid surfaces, and the effects on fluids in the presence of an electric field (Batchelor, 1996). Many of his works have been published in the world-renowned Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences. A variety of honours were bestowed upon Taylor throughout his life. In 1919, Taylor was elected a Fellow of the Royal Society and was knighted in 1944 after winning the Copley Medal for his "many contributions to aerodynamics, hydrodynamics, and the structure of metals, which have had a profound influence on the advance of physical science and its applications" (Batchelor, 1976).

8.2 The Personal Life and Work of Sir G. I. Taylor

Taylor was born in London, England on March 7, 1886. His father, Edward Ingram Taylor, was an artist and his mother, Margaret Boole, came from a family of mathematicians. Not only an English mathematician, Margaret Boole was also an educator, philosopher, and logician. His grandfather, George Boole, was the originator of Boolean algebra (Batchelor, 1996). Boolean logic was credited with laying the foundations for the information age. His grandfather became one of the biggest influences on Sir Taylor's childhood. This encouraged Taylor's fascination with science when he was only a child. Unsurprisingly, Sir Taylor followed his grandfather's footsteps and studied mathematics at Trinity College in Cambridge.

The first time Taylor was attracted to science was the period in preparatory school in Hampstead. X-rays had recently been discovered, and he was able to obtain a small X-ray bulb which had been made as a present for his aunt Lucy Boole by a glassblower to generate X-rays of low intensity (Batchelor, 1996). Being the grandson of George Boole, Taylor was introduced to mathematician and physicist Lord Kelvin.

Before the World War I, Taylor found himself working in the fundamental particle physics at the Cavendish Laboratory. For the next sixty years he made significant contributions to the fields of fluid and solid mechanics, including meteorology, physical oceanography, fracture mechanics, plasticity, and turbulence (Batchelor, 1996).

As a pronounced meteorologist after the sinking of the Titanic, Taylor boarded the Ice Patrol vessel Scotia whose mission was to observe icebergs in the North Atlantic Ocean (Batchelor, 1976). Here he was given the opportunity to study the characteristics of turbulent air motion at different elevations above sea level. During World War I, Taylor was recruited as an aeronautical engineer. Here he solved practical aerodynamic problems and even learned how to fly a plane himself. After the war, Taylor returned to Cambridge to continue his research and became a lecturer at the Trinity College. On August 15, 1925 G. I. Taylor married Grace Stephanie (Batchelor, 1996). During World War II, Taylor was on the front line of science once again. Sent to serve at Los Alamos, Taylor worked on the Manhattan Project and also on many technical committees. His work included a series of physical applications including wave propagation, solid mechanics, and explosions (Turner, 1997).

After the Allied War and his retirement as a professor, Taylor solely dedicated his time to research. It was stated that Taylor had made scientific and mathematical advancements in every scientific field at the time (Batchelor, 1996). During the years of his retirement he continued providing new research, while his age did not seem to make a difference in his ability to think creatively (Turner, 1997). Many of the papers he had written (for example longitudinal discrete papers in the flow of fluids through pipes) were fundamental to future discoveries in their respective fields, leading to numerous awards and honours.

8.3 Wartime Research of Sir G. I. Taylor

Geoffrey Ingram Taylor was first and foremost a physicist and mathematician, but in the two darkest periods of modern history Dr. Taylor showed no hesitation when called to serve his country. Geoffrey was never a soldier nor saw combat but his intellectual contributions were pivotal in the Allied War efforts.

In the World War I Geoffrey applied his knowledge of fluid mechanics and aircraft design to investigate the stresses on propeller shafts in early airplanes (Turner, 1997). This was a high priority research at the time since aircraft had just made their debut in warfare. While working at the Royal Aircraft Factory in Farnborough being the adventurous hands-on man Taylor was, he learned to fly airplanes simply so he could experience how planes behave. He then also recorded pressure distribution readings over the wings during flight. Through all this excitement his focus remained on torsion on the propeller shaft specifically the keyway cuts made into them. Interestingly enough, this line of experimentation seeded his curiosity in the strength of crystalline structures, which would eventually lead to his groundbreaking theories in dislocation mechanisms and plastic deformation in crystals (Turner, 1997). This line of questioning would be motivation for his research at Cambridge in-between the wars.

With the outbreak of the World War II Geoffrey was in high demand due to his extensive research in solid mechanics and shock waves (Batchelor, 1976). During World War II Dr. Taylor's research revolved around the detonation of solids and their resulting blast waves. Through vigorous experimentation Geoffrey successfully developed a model for pressure-time relations at different distances from a blast (Turner, 1997). This relationship would eventually lead to his models of the structure of residual blast waves (Batchelor, 1976). In later years Dr. Taylor was even able to produce a model to estimate the yield of an atomic device from no more than twenty still-frame photographs taken of the American test at Los Alamos (Turner, 1997). This was done by observing the rate of expanse of the fireball aided by an ensemble of equations and assumptions about shock wave behaviour. At the time the actual yield of the device was classified, but in later years his model was found to be extremely close to the recorded strength (Turner, 1997).

The immense power of atomic weapons lead him to his research on the rise of massive plumes in the atmosphere, possibly a result of an atomic blast (Batchelor, 1976). Around the same time Geoffrey began to investigate underwater explosions and the effects they have based on object orientation to the blast (Turner, 1997). He discovered that objects directly above the blast experience more force than those placed to the side even though blast wave propagation is spherically symmetrical. His continued experimentation would eventually lead to the explanation of cavitation on high-speed ship hauls and propellers (Batchelor, 1976). Although Geoffrey did not apply his work directly to the war efforts, his contributions to wave theory and solid mechanics lead to amazing innovations in understanding the natural world that still help engineers today.

8.4 Conclusion

In 1972 Taylor would suffer his first stroke. This time was strenuous for Taylor as his ability to conduct experiments was limited for some time. Shortly after, Taylor passed away in his home in Cambridge due to a second stroke on June 27, 1975. Behind Taylor's great scientific achievement and quest for adventure was a man who was described by his peers as modest and gentle. He had a lovely curiosity as a bright child and kept this attitude in his life up until his eighties. He had a talent for working or unselfishly dealing with any job or problem in science or non-science. In March 1986, to commemorate his 100^{th} birthday, at an international symposium in Cambridge, the estate was represented as 'the fluid mechanics of Taylor's essence'. The legacy contains admonitions to scientists, especially those engaged in training young people (Batchelor, 1996).

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.

Mohsen Moradi has received his masters degrees in 2014 in Aerospace Engineering from University of Tehran with a specialization in wind engineering. He has completed his bachelor's degree in 2012 in the general field of fluid mechanics. His Ph.D. research currently focuses on developing fast and accurate Urban Atmospheric Models (UAMs) at the School of Engineering, University of Guelph. UAMs are capable of predicting the urban micro-climate and pollution dispersion and being integrated in large mesoscale weather forecast and air quality models. Mohsen 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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