Introduction to Engineering Thought

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SUMMARY BOOK PROPOSAL

Objectives

Introduction to Engineering Thought will be an undergraduate-level textbook to be used in an introduction to engineering course, commonly taught at the freshman or sophomore university levels. It provides the student with an historical perspective of the evolution of engineering thought and processes, using case histories to allow the student to "get inside the head" of engineers as they attempt to solve the difficult problems of their day. Engineering requires a large skill set and complicated analysis processes to construct design solutions that must accommodate a wide set of both technical and societal constraints. The objectives of this book, therefore, are for engineering students to learn how these technical and societal factors impact the design process, and how to use historical case studies as engineering design and decision-making tools.

The book will highlight the many ethical and societal problems that are involved with the engineering profession, and will bring in aspects of science, mathematics, psychology, sociology, political science, economics, etc., that impact the engineering process. These areas are ABET criteria for accreditation and are frequently difficult for schools to illustrate where they are taught. The book will include end-of-chapter questions for the student to conduct more in-depth (frequently web based) research on particular individuals and their contributions.

Market

The book is aimed at freshman and sophomore introductory courses to engineering. There is a great need for today's engineering students to understand the history of the profession and how the thinking and our processes have evolved over time. This book will attempt to trace through selective case histories on individuals and projects that have dictated how we do engineering today and how we are evolving as a profession.

There are few introductory books on engineering on the market today. These books typically include a wide array of topics, often focusing on design, ethics and high school-level discussions of physical principles and elementary mathematics and statistics. The emphasis on design in the freshman course is misplaced, in our view, as the student does not yet have the skill set to work on any complex system in a meaningful way at this point his his/her studies. This book helps build that skill set by providing meaningful case histories that allow them to understand the complexity of the decision-making involved.

General Structure

The book will have 10 chapters plus introduction, bibliography and index, about 300 pages or 100,000 words total. Each chapter will be about 25 pages long with 4-6 B&W figures, containing two case histories plus student discussion questions at the end. Each chapter will focus on a specific topic area and revolve around two case histories, separated by both time and culture. The case studies will examine the background of the principle characters (engineers), show how the engineers and their contemporaries thought about the problems to be solved, and show how they arrived at the engineering solutions. Each case study will use original writings from the principal characters and their contemporaries, as well as modern analysis. Student questions will compare and contrast the engineering approaches taken by the different characters, and examine how their thought processes were influenced by their era, culture, nature of the problem and understanding of the principles involved.

Book Outline

Introduction: Explanation of book, structure, nature of intended course

1. Laws We Live By: Overview of scientific and mathematical principles that govern how engineers think.
2. Position and Time: The Problem of Longitude (John Harrison, UK 1750); Global Positioning System (Brad Parkinson, USA 1990).
3. Bridges: Britannia Tubular Bridge (John Fairbairn, UK 1850); Tacoma Narrows Bridge (Leon Moisseiff and Theodore von Karman, USA 1940).
4. Energy: Steam engines, mechanized looms and industrialization (James Watt, Edmund Cartwright and "Ned Ludd", UK 1810); The Current Wars (Thomas Edison, George Westinghouse and Nikola Tesla, USA 1910).
5. Land Transportation: Railroad Gauge Wars (Robert Stephenson and Isambard Kingdom Brunel, UK 1840); American Highway System (Henry Ford, Thomas MacDonald and Dwight Eisenhower, USA 1920-1960).
6. Ocean Transportation: Steamship Great Eastern (Isambard Kingdom Brunel and John Scott Russell, UK 1858); Nuclear submarine Nautilus (Hyman Rickover, USA 1954).
7. Air Transportation: First Powered Flight (Wright Brothers, Glenn Curtis and French competition, 1900-1910); U-2 and A-12 (Kelly Johnson, 1955 USA).
8. Communications Networks: Telegraph (Samuel Morse, USA 1840); ARPANET (Robert Kahn, Vincent Cerf etc., USA 1970)
9. Computing: Bletchley Park Codebreakers (Alan Turing, UK 1940); Personal Computers (Stephen Wozniak, etc. 1970 USA).
10. Systems Engineering: Polaris SLBM project (William Raborn, USA 1956): NASA and Apollo (Wehrner von Braun, USA 1965).

Bibliography of important references, by chapter

Index

Authors

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Publication Timeline

Draft of three chapters to be completed by December 2011. Final draft completed by fall 2013. Anticipated publication date 2014.

Sample of Introduction and Chapter one Draft follows.

Introduction

Who are our engineering heroes? What were the societal frameworks within which they worked? Why did they develop the designs that have made them famous? How were they educated or trained? What were the main problems they had to overcome?

Most high school students have studied mathematics at least through algebra and geometry and science (biology, chemistry and physics). We all know about the famous Greek mathematicians and many of the famous scientists in these fields (e.g. Pascal, Newton, Einstein, etc.). But engineering is, of necessity, much more complex and is not generally treated in high school. We have encountered many freshman engineers who know little to nothing about how engineering is different from science. Unfortunately, in our zeal to begin teaching our engineering philosophy and methods, we have failed to teach our history. This book is intended to make up for this oversight and give both high school students, university freshmen and practicing professionals a selective snap-shot of some of the major players in a long and complex history that has shaped our modern world and will shape the future, for better or worse. This is not intended to be either complete or comprehensive, that would be a much larger book.

We have selected a number of case studies that involve individuals, teams and projects that have provided significant engineering designs at critical times in the development of recorded history. Some individuals discussed developed the concepts and equations that are the foundation for our contemporary designs. Some were more involved in the actual designs themselves; some are noteworthy because they recorded their designs and the design principles and methods for others to follow.

One of the reasons that engineering is difficult to categorize is that it is intimately involved with other fields of endeavor. Professor Hardy Cross, in *Engineers and Ivory Towers*, has generalized the position of engineering:

"***It is customary to think of engineering as a part of a trilogy, pure science, applied science, and engineering. It needs emphasis that this trilogy is only one of a triad of trilogies into which engineering fits. The first is pure science, applied science, engineering; the second is economic theory, finance and engineering; and the third is social relations, industrial relations, and engineering. Many engineering problems are as closely allied to social problems as they are to pure science.”***

As you can see, engineering covers a wide range of activities and is therefore difficult to define. The 1953 Stanford University Committee on Evaluation of Engineering Education, (J. of Eng. Ed. Vol, made a definition that we like. 44, p.258, Dec. 1953):

“By and large engineers are paid by society to work on systems dealing with problems whose solutions are of interest to that society. These systems seem to group conveniently into (a) systems for material handling, including transformation of and conservation of raw and

processed materials; (b) systems for energy handling, including its transformation, transmission, and control; and (c) systems for data on information handling, involving its collection, transmission, and processing."

"In carrying out this work engineers engage in various activities ranging through engineering research, design and development, construction, operation, and management."

David Billington has pointed out in his 3 excellent books (Princeton, 1983, Wiley, 1996, and Princeton, 2006) on the history of engineering that there is very little use of what we now consider to be science in most of engineering activity. Billington observes that scientists are inherently looking to the past to better understand what has always been (i.e. the fundamental laws of nature) while engineers are always asked to look to the future to provide something new generated by the desires of society within the constraints of the economics of the project and the fundamental laws of nature. Unfortunately, Billington's books mostly emphasize American contributions post 1776. He also significantly ignores the areas of thermodynamics and information transport. As the complexity of our design problems is increasing, modern computational systems using advanced mathematics may now be playing a more important role than in the past. The search for new energy sources requires today's students to have a fundamental understanding of the history of energy use, efficiency and energy density. Thus, many students may find the works less than relevant to today and tomorrow's problems, important to a successful introduction to engineering textbook.

Unfortunately, we are not able to interview the engineers that have gone before us, thus we draw from a wide range of historical sources to produce our profiles of these men and women and their design teams. In the area of information and systems engineering, we are fortunate to be able to interview some of the people who have created a revolution in communications, position measurement and information sharing. We would like to record interviews with some of these contemporary individuals to be documented in this book.

An expanded taxonomy is developed for this book to provide a framework to trace the evolution of engineering thought.. The elements of this taxonomy are as follows: 1) sociological framework at the time, 2) economics of the age, 3) state of material properties, 4) the ability to measure time and position, 5) the state of energy density and power transfer, 6) state of transportation speed, 7) state of communication bandwidth, and 8) the state of information storage and transfer.

Key metrics are traced for the following: 1) Time measurement accuracy; 2) Position measurement accuracy; 3) Strength of materials; 4) Energy Density; 5) Communications Bandwidth; 6) Prevalent Social Structure; 7) Prevalent Economic Structure; 8) Transportation Speed. A series of questions are also carried throughout this book: What is the family and educational background of the key individuals discussed; what problem in society was the individual trying to solve; what were the biggest obstacles they had to overcome; what were the tools they relied on in their designs; and finally, what were the long term effects of their designs on society? Finally, a new issue is arising today, "How do we teach and document engineering in an age of increasing technical complexity, cloud computing and data storage? Finally, what is the future of distributed engineering education without the use of physical laboratories and face-to-face team building with both faculty and student peers?"

Chapter One: Laws we Live By

Those who are in love with the practice without knowledge are like the sailor who gets into a ship without rudder or compass and who never can be certain whether he is going

Leonardo da Vinci, Manuscript G,f.8r (circa. 1490)

There are many equations and laws that are used by the various disciplines of modern engineering. Our goal in this chapter is to give the student some historical background on the individuals who have given us some of the most important conservation laws that are the basis for the derivation of many of the other equations that they will encounter as professional engineers.

Archimedes of Syracuse (c.287-212 BCE)

Where do we begin? Engineers have been modifying the world we live in for all of recorded history. Prior to the great Greek mathematician and philosopher Archimedes, little was codified in mathematical language. A recent book by Andre Assis (2010) gives us a good summary of Archimedes life and contribution to the laws that engineers use every day. The two contributions that we will highlight are the mathematical formulation of the Law of Levers and the Archimedes Principle or the Law of Buoyancy. Both of these laws are the foundations of what we refer today as *statics* (the mechanics of solid bodies at rest and in equilibrium) and *hydrostatics*. He also initiated the engineering study of static stability used by mechanical, aerospace and naval architecture engineers.

Archimedes was born and mostly lived in Syracuse, on the coast of Sicily, Italy. He was the son of an astronomer, Pheidias, and spent some time in Egypt, probably Alexandria, the center of Greek science and mathematics at the time. The mathematician Euclid had already published the famous book of geometry known as *The Elements* around 300 BCE. Archimedes is considered one of the greatest engineers of all time and the greatest mathematician of antiquity.

Archimedes was able to determine the area, volume, and center of gravity of many important geometrical figures that are used in everyday engineering calculations today. The relationship between the circumference of a circle divided by it's diameter was known. However, his brilliant calculus like derivation of the value for *pi* of ~22/7 = 3.1429.. is very close to the number we use today.

His treatise on *Measurement of a Circle*, Proposition 3 states: *"The ratio of the circumference of any circle to its diameter is less than 3 1/7 but greater than 3 10/71."*

The fact that forces acted equally on an equal arm balance beam as a means of weighing commodities was well known in 300 BCE. Archimedes extended this knowledge to force balances of unequal length lever arms. Thus the common static force balance on a "solid free body" equations were born. In current notation these can be stated as static equilibrium:

Sum of the Forces F = 0

Sum of the Moments (F x L) = 0

Archimedes is reputed to have told King Hiero when he was ordered to launch a fully loaded ship weighing many tons *"Give me a place to stand on, and I will move the Earth*". The roman historian Plutarch records that King Hiero was so amazed with his successful launching that he said "*From this day forth Archimedes was to be believed in everything he might say*".

Archimedes initial interest in hydrostatics is described by the roman Vitruvius (c. 90-20 BCE) in his book on architecture and engineering:

"Though Archimedes discovered many curious matters that evince great intelligence, that which I am about to mention is the most extraordinary. Hiero, when he obtained the regal power in Syracuse, having, on the fortunate turn of his affairs, decreed a votive crown of gold to be placed in a certain temple to the immortal gods, commanded it to be made of great value, and assigned for this purpose an appropriate weight of the metal to the manufacturer. The latter, in due time, presented the work to the king, beautifully wrought; and the weight appeared to correspond with that of the gold which had been assigned for it.

But a report had been circulated, that some of the gold had been abstracted, and that the deficiency thus caused had been supplied by silver, Hiero was indignant at the fraud, and, unacquainted with the method by which the theft might be detected, requested Archimedes would undertake to give it his attention. Charged with this commission, he by chance went to a bath, and on jumping into the tub, perceived that, just in the proportion that his body became immersed, in the same proportion the water ran out of the vessel. Whence, catching at the method to be adopted for the solution of the proposition, he immediately followed it up, leapt out of the vessel in joy, and returning home naked, cried out with a loud voice he had found that of which he was in search, for he continued exclaiming "I have found it, I have found it"".

He then was able to compare the specific weight of the crown to the specific weight of pure gold and determine that the crown also contained silver. Archimedes' treatise *On floating bodies Book I and II* creates the entire science of hydrostatics. Propositions 5 to 7, can be restated as:

Any floating object displaces its own weight of fluid.

For more general objects, floating and sunken, and in gases as well as liquids (i.e. a fluid), Archimedes' principle may be stated thus in terms of forces:

Any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object. (with the clarifications that for a sunken object the volume of displaced fluid is the volume of the object, and for a floating object on a liquid, the weight of the displaced liquid is the weight of the object.)

More tersely,

Buoyancy force = weight of displaced fluid

Many people today think of Archimedes as a mathematician but in his own time he was more famous as an engineer and builder of war machines. Plutarch also wrote about the roman General Marcellus, who attacked Syracuse in 214 as part of the second Punic war between Rome and Carthage. The Syracuse king had requested that Archimedes reduce his designs to practice. Archimedes directed that great stone throwing catapults and other anti-ship machines be constructed which would be used against the siege ships of the romans. Plutarch states that Archimedes' machines blunted the initial assault by General Marcellus which led to a 3 year siege of the city. Although General Marcellus had given express ordered for Archimedes to be captured alive, he was killed by a Roman soldier in 212.

Archimedes did not deal with bodies or fluids in motion. His static equations, however, have served engineers for over 2000 years. The noted Roman aqueduct engineer, Sextus Julius Frontinus, added the dynamic observation in 97 C.E. that " *water always flows downhill, never uphill and that the amount of water a pipe can deliver depends on the size of its opening*". These observations allowed the romans to design great aqueduct systems but provided little insight into the more important laws that were to follow. The next person to add to his observations and to extend them to moving fluids was Leonardo da Vinci in the late 15th century.

Leonardo da Vinci (c. 1452-1519 CE)

Leonardo was born in Vinci, Italy on Saturday, 15 April, 1452, at 10:30 pm. the illegitimate child of Ser Piero da Vinci, a notary who worked mostly in Pisa and Florence. His mother was a local beautiful Vinci peasant girl named Caterina but he was raised by his grandparents. As an illegitimate son, Leonardo was barred from attending university and could not hope to enter any of the respected professions, such as medicine or law. Leonardo always resented his lack of a formal education. Leonardo began his apprenticeship at age 17 in Florence around 1469 in Verrocchio's art studio.

By this date, Gutenberg had been printing books for 14 years starting in 1455. There was a growing awareness of the lost knowledge of the Greeks and Romans by this time in Florence, the center of the Renaissance. By 1500, some forty thousand different titles had been printed by over one thousand printers in Europe. Although Greek and Latin remained the language of the educated, the Roman and Greek numbering systems were not up to the challenges that now presented themselves to scientists and engineers. It was also about this time that Europeans adopted the Hindu-Arabic numeral system. This system is critical to the development of engineering calculations and is based on a decimal place-value number system that uses zero to handle the empty powers of ten. This system was probably first developed by the Chinese mathematician Sun Tzu between the 3rd and 5th centuries CE.

Leonardo spent 16 years in Florence under the tutelage of the great Florentine sculptor and painter, Verrocchio. By 1472 at age 20, he was registered a Master member of the painter's guild. Another early influence on Leonardo's technical and artistic intellectual development was Leon Alberti, also born out of wedlock in 1407. Alberti was a believer in conducting his own experiments and documenting his observations. Leonardo developed an abiding lack of respect for authority which limited his artistic commissions and fruitful political relationships. As early as the late 1470s he began illustrating the design of war machines and the flow of fluids.

In 1482, Leonardo moved to Milan to apply for the position as the Duke's chief city and military engineer. He spent almost 20 of the happiest years of his life in Milan. Throughout his life, Leonardo frequently neglected to finish artistic commissions in favor of pursuing his engineering interests. After his second stay in Milan, Leonardo left for Rome and then Cloux, France where he died working for King Francis I on 2 May 1519 at the age of 67. Unfortunately, Leonardo never published his manuscripts and many were lost. His remaining works were not re-discovered until the 18th century. This raises the important issue of how engineers record and archive important findings and designs in the world of soft copies and cloud computing.

The study of fluid motion was a lifelong passion. Leonardo did extensive straw-on-water flow visualization studies of river fluid flows. His remaining notes record that he observed that the water's speed increased in direct proportion to the narrowing of the bottlenecks in a stream. He has thus been credited with being the first to codify the "Law of Continuity" for river flows (an incompressible fluid) where A= area and *v*=velocity:

$$\mathbf{A_1 \mathit{v}_1 = A_2 \mathit{v}_2.}$$

Antoine Lavoisier (1743-94) expanded on this "**conservation of mass**" observation in the late 18th century before he was executed by the French revolution. As with Archimedes, Leonardo understood that both liquids and gases were both controlled by these laws and should be considered commonly as "fluids" and this is the first equation in the Navier-Stokes equations that we use today in mechanical, chemical, and aerospace engineering. It took over 100 years before

Robert Boyle and Isaac Newton would be born in northern Europe to make the next major advance in the development of engineering equations.

Robert Boyle (1627-1691 CE)

Boyle was born in Lismore Castle, in County Waterford, Ireland, the seventh son and fourteenth child of Richard Boyle, 1st Earl of Cork and Catherine Fenton on January 25, 1627. Richard Boyle arrived in Dublin from England in 1588 and obtained an appointment as a deputy escheator. He had amassed enormous landholdings by the time Robert was born. As a child, Robert was raised by a local family, as were his elder brothers. Consequently, the eldest of the Boyle children had sufficient Irish at four years of age to act as a translator for his father. Robert received private tutoring in Latin, Greek and French and when he was eight years old, following the death of his mother, he was sent to Eton College in England. His father's friend, Sir Henry Wotton, was then the provost of the college.

After spending over three years at Eton, Robert traveled abroad with a French tutor. They visited Italy in 1641 and remained in Florence during the winter of that year studying the "paradoxes of the great star-gazer" Galileo Galilei, who was elderly but still living in 1641.

Boyle returned to England from Continental Europe in mid-1644 at the age of 17 with an interest for scientific research. His father had died the previous year and had left him the manor of Stalbridge in Dorset, England and substantial estates in County Limerick. Robert devoted the rest his life to scientific research and soon took a prominent place in the group known as the "Invisible College", who devoted themselves to the cultivation of the "new philosophy". They met frequently in London, often at Gresham College, and some of the members also had meetings at Oxford.

Having made several visits to his Irish estates beginning in 1647, Robert moved to Ireland in 1652 but became frustrated at his inability to make progress in his chemical research. In one letter, he described Ireland as *"a barbarous country where chemical spirits were so misunderstood and chemical instruments so unprocurable that it was hard to have any Hermetic thoughts in it."*

In 1654, Boyle left Ireland for Oxford to pursue his work more successfully. An inscription can be found on the wall of University College, High Street, marking the spot where Cross Hall stood until the early 19th century. It was here that Boyle rented rooms from the wealthy apothecary who owned the Hall.

Reading in 1657 of Otto von Guericke's air-pump, he collaborated with Robert Hooke to improve its design and construct the "machina Boyleana" or "Pneumatical Engine", finished in 1659. He then began a series of experiments on the properties of air. An account of Boyle's work with the air pump was published in 1660 under the title *New Experiments Physico-Mechanicall, Touching the Spring of the Air, and its Effects....*

A Jesuit priest, Francis Line (1595–1675) criticized his views, and it was while answering his objections that Boyle made his first mention of the law that the volume of a gas varies inversely to the pressure of the gas, now referred to as Boyle's Law. The person that originally formulated the hypothesis was Henry Power in 1661. Boyle included a reference to a paper written by Power, but mistakenly attributed it to Richard Towneley.

In 1663 the Invisible College became the Royal Society of London for the Improvement of Natural Knowledge, and the charter of incorporation granted by Charles II of England, named Boyle a member of the council. In 1680 at age 53 he was elected president of the society, but declined the honor from a scruple about oaths.

It was during his time at Oxford that Boyle became a *Chevalier*. The Chevaliers are thought to have been established by royal order a few years before Boyle's time at Oxford. The early part of Boyle's residence was marked by the actions of the victorious parliamentarian forces, consequently this period marked the most secretive period of Chevalier movements and thus little is known about Boyle's involvement beyond his membership.

In 1689 his health, never very strong, began to fail seriously and he gradually withdrew from his public engagements, ceasing his communications to the Royal Society, and advertising his desire to be excused from receiving guests. His health became still worse in 1691, and he died on 31 December at the age of 64, just a week after that of the sister with whom he had lived for more than twenty years. Robert Boyle died from paralysis. He was buried in the churchyard of St Martin in the Fields, his funeral sermon being preached by his friend Bishop Gilbert Burnet. In his will, Boyle endowed a series of Lectures which came to be known as the Boyle Lectures.

His most important contribution to engineering is Boyle’s Law:

$$\mathbf{pV = constant}$$

where:

p denotes the pressure of the system.

V denotes the volume of the gas.

Boyle's law is used to predict the result of introducing a change in volume and pressure, at constant temperature, to the initial state of a fixed quantity of gas. Heating or cooling will be required to meet this condition. This law states that the number of gas molecules is conserved in a closed vessel.

Combining Boyle's law with the addition of temperature (T) in Charles's law we can form the combined gas law.

$$pV/T=constant$$

Today this sometimes is referred to as an equation of state and is one of the principle equations used by mechanical and chemical engineers. In particular, this equation is critical to understanding the design of steam engines that produce a majority of the electric power used today.

Isaac Newton (1642-1727 CE)

Boyle was 15 years old, studying in Florence, when Isaac was born to Hanna Newton on December 25, 1642 in Woolsthorpe, Lincolnshire, England. Hanna had been recently widowed from her 36 year old husband, also named Isaac, who was killed as a soldier defending the catholic King Charles I from a rebellion by parliament. The young Isaac was born premature and gave every indication that he would not survive. For his first few years of life he had to wear a neck brace to hold his head in place. When he was two years old, however, his mother married the 66 year old Rev. Barnabas Smith from North Witham. She moved to his town and left Isaac to be raised by her mother.

He began to attend school in 1649, the year that the Puritan-dominated Parliament, led by Oliver Cromwell, defeated the royal armies and King Charles I was beheaded. When his mother returned home, a new widow with a new inheritance, the relationship between Isaac and his mother was very strained. At twelve, Isaac left home to attend grammar school in Grantham city. At 17, his mother pulled him out of school and brought him back to Woolsthorpe to help run the family farm, with the strenuous objections of his teachers and uncle. Fortunately for history, Isaac was a very poor farmer and was sent back to finish his grammar schooling in only nine months in 1661. On the strong recommendations of his teachers, Isaac was accepted into Trinity College of Cambridge University (founded in 1546 by King Henry VIII) at the age of 18. Although his mother could afford to fund his tuition, she refused and he was required to be enrolled into the college as a subsizar. This required Isaac to pay for his education as a part-time servant, emptying chamber pots, grooming his master’s hair and hauling firewood. In 1664, he was bedridden with exhaustion and did not do well with his final exams. In spite of his poor exam performance, he was admitted to a master’s program on the recommendation of some of the faculty. His studies were interrupted by the Black Plague of the summer of 1665 and he was forced to return to his home at age 22 to Woolsthorpe.

In 1667, he returned to Cambridge as a fellow of Trinity. Fellows were required to become ordained Church of England priests, something Newton desired to avoid due to his non-Anglican religious views. There was no specific deadline for ordination, however, and it could be postponed indefinitely. The problem became more severe later when Newton was elected to the prestigious Lucasian Chair. For such a significant appointment, ordaining normally could not be dodged. Nevertheless, Newton managed to avoid it by means of a special permission from Charles II.

Most modern historians believe that Newton and Leibniz developed calculus independently, although with very different notations. Newton published almost nothing until *Principia* was published on July 5, 1687 and in its forerunner manuscripts, such as *On the motion of bodies in orbit*, of 1684. Leibniz began publishing a full account of his methods in 1684. (Leibniz's notation and "differential Method" are now recognized as much more convenient notations.

Newton had been reluctant to publish his calculus because he feared controversy and criticism. Starting in 1699, other members of the Royal Society (of which Newton was a member) accused Leibniz of plagiarism, and the dispute broke out in full force in 1711. The Royal Society proclaimed in a study that it was Newton who was the true discoverer and accused Leibniz of being a fraud. This study was cast into doubt when it was later found that Newton himself wrote the study's concluding remarks on Leibniz. Thus began the bitter controversy which marred the lives of both Newton and Leibniz until the latter's death in 1716.

Newton's three laws of motion that are most used by engineers describe the vector relationship between the forces acting on a body and its motion due to those forces and can be summarized as follows:

1. **First law**: In a vacuum, the velocity of a body remains constant unless the body is acted upon by an external force, The Law of the “Conservation of momentum”,

   $$m\mathbf{v} = \textbf{constant}$$

2. **Second law**: The acceleration **a** of a body is parallel and directly proportional to the net force **F** and inversely proportional to the mass ***m***,

   $$\mathbf{F} = m\mathbf{a}.$$

3. **Third law**: The mutual forces of action and reaction between two bodies are equal, opposite and collinear. This extends Archimedes static law of levers to a vector equation.

The vector nature of the three laws address the geometrical relationship between the direction of the force and the manner in which the object's momentum changes. These are the fundamental equations that engineers use in the study of *dynamics*. Newton also recognized the linear relationship between a sheer stress in a simple fluid (like water) and the velocity gradient normal to a wall. When this observation is combined with the vector Conservation of Momentum for fluids, we have the foundations of the Navier-Stokes equations used in fluid mechanics. Newton died in the early morning of 20 March, 1727 and was buried in Westminster Abbey at the age of 85. Although he outlived his rival, Leibniz, by 11 years, he is reputed to have said near the end of his life, ***"If I have seen further, it is by standing on the shoulders of Giants".*** This has always been true for all scientists and engineers.

Newton extended the *static* world of Archimedes to include *dynamic motion*. He primarily dealt with the Conservation of Forces, Momentum and the Inertia of solid bodies, however. It was up to Leibnitz and Daniel Bernoulli to recognize that energy must also be conserved for both solids and fluids.

Gottfried Wilhelm Leibniz (1646-1716 CE)

Eight years after the birth of Newton, Gottfried Leibniz was born on July 1, 1646 in Leipzig, Saxony (at the end of the Thirty Years' War), to Friedrich Leibniz and Catherina Schmuck. Leibniz's father died when he was six years old, and from that point on, he was raised by his mother. Her teachings influenced Leibniz's philosophical thoughts in his later life.

Leibniz's father, Friedrich Leibniz, had been a Professor of Moral Philosophy at the University of Leipzig, so Leibniz inherited his father's personal library. He was given free access to this from the age of seven and thereafter. While Leibniz's schoolwork focused on a small canon of authorities, his father's library enabled him to study a wide variety of advanced philosophical and theological works – ones that he would not have otherwise been able to read until his college years. Access to his father's library, largely written in Latin, also led to his proficiency in the Latin language. Leibniz was proficient in Latin by the age of 12, and he composed three hundred hexameters of Latin verse in a single morning for a special event at school at the age of 13.

He enrolled in his father's former university at age 14, and he completed his bachelor's degree in philosophy in December of 1662 at the age of 16! He defended his *Disputatio Metaphysica de Principio Individui,* which addressed the Principle of individuation, on June 9, 1663. Leibniz earned his master's degree in philosophy on February 7, 1664, at the age of 18. He published and defended a dissertation *Specimen Quaestionum Philosophicarum ex Jure collectarum*, arguing for both a theoretical and a pedagogical relationship between philosophy and law, in December 1664. After one year of legal studies, he was awarded his bachelor's degree in Law on September 28, 1665.

In 1666, Leibniz published his first book, *On the Art of Combinations,* the first part of which was also his thesis in philosophy. His next goal was to earn his license and doctorate in Law, which normally required three years of study then. Older students in the law school blocked his early graduation plans, prompting Leibniz to leave Leipzig in disgust in September of 1666.

Leibniz then enrolled in the University of Altdorf, and almost immediately he submitted a thesis, which he had probably been working on earlier in Leipzig. The title of his thesis was *Disputatio de Casibus perplexis in Jure.* Leibniz earned his license to practice law and his Doctorate in Law in November of 1666. He next declined the offer of an academic appointment at Altdorf, and he spent the rest of his life in the paid service of two main German noble families.

Leibniz's first position was as a salaried alchemist in Nuremberg, even though he knew nothing about the subject. He soon met Johann Christian von Boineburg (1622–1672), the dismissed chief minister of the Elector of Mainz, Johann Philipp von Schönborn. Von Boineburg hired Leibniz as an assistant, and shortly thereafter reconciled with the Elector and introduced Leibniz to him. Leibniz then dedicated an essay on law to the Elector in the hope of obtaining employment. The stratagem worked, the Elector asked Leibniz to assist with the redrafting of the legal code for his Electorate. In 1669, Leibniz was appointed Assessor in the Court of Appeal. Although von Boineburg died late in 1672, Leibniz remained under the employment of his widow until she dismissed him in 1674.

Von Boineburg did much to promote Leibniz's reputation, and the latter's memoranda and letters began to attract favorable notice. Leibniz's service to the Elector soon followed a diplomatic role. He published an essay, under the pseudonym of a fictitious Polish nobleman, arguing (unsuccessfully) for the German candidate for the Polish crown. The main European geopolitical reality during Leibniz's adult life was the ambition of Louis XIV of France, backed by French military and economic might. Meanwhile, the Thirty Years' War had left German-speaking Europe exhausted, fragmented, and economically backward. Leibniz proposed to protect German-speaking Europe by distracting Louis as follows. France would be invited to take Egypt as a stepping stone towards an eventual conquest of the Dutch East Indies. In return, France would agree to leave Germany and the Netherlands undisturbed. This plan obtained the Elector's cautious support. In 1672, the French government invited Leibniz to Paris for discussion, but the plan was soon overtaken by the outbreak of the Franco-Dutch War and became irrelevant. Napoleon's failed invasion of Egypt in 1798 can be seen as an unwitting implementation of Leibniz's plan.

When it became clear that France would not implement its part of Leibniz's Egyptian plan, the Elector sent his nephew, escorted by Leibniz, on a related mission to the English government in London, early in 1673. There Leibniz came into acquaintance of Henry Oldenburg and John Collins. After demonstrating a calculating machine he had been designing and building since 1670 to the Royal Society, the first such machine that could execute all four basic arithmetical operations, the Society made him an external member. The mission ended abruptly when news reached it of the Elector's death, whereupon Leibniz promptly returned to Paris and not, as had been planned, to Mainz.

Thus Leibniz began several years in Paris. Soon after arriving, he met Dutch physicist and mathematician Christiaan Huygens and realized that his own knowledge of mathematics and physics was patchy. With Huygens as mentor, he began a program of self-study that soon pushed him to making major contributions to both subjects, including inventing his version of the differential and integral calculus. He also became acquainted with Johann Bernoulli, a mathematician and they corresponded for the rest of their lives. In 1675, at the age of 29, he was admitted as a foreign honorary member of the French Academy of Sciences, which he continued to follow mostly by correspondence.

Leibniz managed to delay his arrival in Hanover until the end of 1676, after making one more short journey to London, where he possibly was shown some of Newton's unpublished work on the calculus. This fact was deemed evidence supporting the accusation, made decades later, that he had stolen the calculus from Newton.

In 1677, he was promoted, at his request, to Privy Counselor of Justice, a post he held for the rest of his life. Leibniz served three consecutive rulers of the House of Brunswick as historian, political adviser, and most consequentially, as librarian of the ducal library. He thenceforth employed his pen on all the various political, historical, and theological matters involving the House of Brunswick.

The Brunswicks tolerated the enormous effort Leibniz devoted to intellectual pursuits unrelated to his duties as a courtier, pursuits such as perfecting the calculus, writing about other mathematics, logic, physics, and philosophy, and keeping up a vast correspondence. He began working on the calculus in 1674; the earliest evidence of its use in his surviving notebooks is 1675. By 1677 he had a coherent system in hand, but did not publish it until 1684. Leibniz's most important mathematical papers were published between 1682 and 1692, usually in a journal which he and Otto Mencke founded in 1682, the *Acta Eruditorum*. That journal played a key role in advancing his mathematical and scientific reputation, which in turn enhanced his eminence in diplomacy, history, theology, and philosophy

In 1711, John Keill, writing in the journal of the Royal Society and with Newton's presumed blessing, accused Leibniz of having plagiarized Newton's calculus. Thus began the calculus priority dispute which darkened the remainder of Leibniz's life. A formal investigation by the Royal Society (in which Newton was an unacknowledged participant), undertaken in response to Leibniz's demand for a retraction, upheld Keill's charge. Historians of mathematics writing since 1900 have tended to acquit Leibniz, pointing to important differences between Leibniz's and Newton's versions of the calculus.

Leibniz contributed a fair amount to the statics and dynamics emerging about him, often disagreeing with Descartes and Newton. He expanded on the new theory of motion (*dynamics*) based on kinetic energy and potential energy, which posited space as relative, whereas Newton felt strongly space was absolute. An important example of Leibniz's mature physical thinking is his *Specimen Dynamicum* of 1695.

Leibniz's *vis viva* (Latin for *living force*) is $\boldsymbol{mv^2}$, twice the modern kinetic energy. He realized that the total energy would be conserved in certain mechanical systems, so he considered it an innate motive characteristic of matter. Written as the "Law of *Vis Viva* Conservation":

Altitude + *Vis Viva* = Constant

Today, we state this as the "Law of Conservation of Energy" for solid bodies:

Potential Energy + Kinetic Energy = Constant

This idea gave rise to another regrettable nationalistic dispute. His *vis viva* was seen as rivaling the ***conservation of momentum*** championed by Newton in England and by Descartes in France. Because of this apparent contradiction, academics in those countries tended to neglect Leibniz's idea. Today we know that ***both energy and momentum are conserved for mechanical systems***, so the two approaches are equally valid.

Leibniz died in Hanover in 1716, at the age of 70. At the time, he was so out of favor due to the controversy between England and the Netherlands over the development of the calculus, that neither George I (who happened to be near Hanover at the time) nor any fellow courtier other than his personal secretary attended the funeral. Even though Leibniz was a life member of the Royal Society and the Berlin Academy of Sciences, neither organization saw fit to honor his passing. His grave went unmarked for more than 50 years. Leibniz was eulogized by Fontenelle, before the Academie des Sciences in Paris, which had admitted him as a foreign member in 1700. His ideas on the conservation of mechanical energy were a major influence on Daniel Bernoulli, who extended the concept of conservation of energy to fluid flow.

Daniel Bernoulli (1700-1782 CE)

Daniel Bernoulli was born in Groningen, in the Netherlands, into a family of distinguished mathematicians on 8 February, 1700. The son of Johann Bernoulli (born 1667) who was chairman of the mathematics department at Groningen University. As a Huguenot, however, he was persecuted by the catholic majority. In 1705, Johann took his deceased brother's professorship at the University of Basil, Switzerland. Johann and Jakob were some of the early supporters of Leibnitz's *vis vita* and calculus and Liebniz considered Johann to be one of his closest friends. Johann's deceased brother, Jakob Bernoulli, was the first to discover the theory of probability. Johann followed the teachings of John Calvin who believed that God had a master plan and each of his sons were to play a predetermined role. From the beginning, Daniel had a very bad relationship with his father, Johann.

When Daniel was seven, his younger brother Johann II Bernoulli was born. Around schooling age, his father, Johann Bernoulli, encouraged him to study business, there being poor rewards awaiting a mathematician. However, Daniel refused, because he wanted to study mathematics. He later gave in to his father's wish and studied business but he was clearly not cut out to be a merchant. His father then asked him to study in medicine, and Daniel agreed under the condition that his father and older brother Nikolaus II would teach him mathematics privately, which they continued for some time. Daniel graduated from university when he was only 15 years old and a year later in 1716 earned his master's degree and began the study of medicine.

Although the understanding of both the statics and dynamics of solid bodies was becoming clear by 1721, the understanding of the measurement and the mathematical description of the motion of fluids was not. The problem of water streaming from a hole in the bottom of a drinking cup was unable to be described with mathematics at this time. Daniel completed his medical studies at the age of 21 in 1721 with his doctoral dissertation concerned with the mechanics of human respiration. In 1723, Daniel left Basel, having failed to win a university professorship.

While recovering from an illness in Padua, Italy, he entered the French Academy of Sciences annual completion in mathematics. The contest had been established in 1666 by King Louis XIV and scores of engineers, mathematicians and laypeople had competed for the monetary award. The problem was to design a ship's hourglass that would produce a reliable trickle of sand or water even when tossed from side to side by rough seas. (This problem will be discussed in more detail later in chapter 2). Daniel proposed to mount the hour glass on a steel plate and to float this in a bowl of mercury. To his surprise, Daniel won first prize at the age of 24, much to the chagrin of his father.

His earliest mathematical work was the *Exercitationes* (*Mathematical Exercises*), published in 1724 with the help of Goldbach. Two years later he pointed out for the first time the frequent desirability of resolving a compound motion into motions of translation and motions of rotation.

Based on his growing fame as a mathematician, Empress Catherine the I of Russia invited him to become professor of mathematics at the new Imperial Academy of Sciences in St. Petersburg. He accepted on the condition that his brother Nikolaus II also be granted a professorship and they both left for St. Petersburg in 1725. Due to the foul weather, his brother died of tuberculosis a year later. In order to find some companionship, Daniel invited a new young protégé of his father, Leonhard Euler, to join him. The year of Newton's death (1727) was also the year that 19 year old Euler joined him at the Academy, just after having won a Certificate of Merit in the French academy's annual completion. Over many years of friendship and collaboration, Euler proved to be more of a pure mathematician while Daniel liked to work both in the laboratory doing experiments and deriving mathematical equations.

It was the study of the human respiration and blood flow problem (as well as the search at the time to better understand the motion of fluids) that led to his famous equation for the "Conservation of Energy" for a fluid. Daniel complained that "*Those who have spoken about the pressure of water flowing through aqueducts [Frontinus] did not hand down any laws other than those for extended fluids with no motion [Archimedes]"*. His equation came out of experimental observations on the measurement of pressure in a person's blood arteries. He observed that the height of a fluid in a measuring tube was related to the velocity of the fluid. When he coupled these observations with the work of Leibnitz on conservation of mechanical energy he postulated that fluids also conserved energy:

$$\textbf{Pressure} + \boldsymbol{rho}\ \boldsymbol{v}^2 = \textbf{Constant}$$

Where ***rho*** is the fluid density and ***v*** is the fluid velocity.

This was later changed by the German Gustave Gaspard a century later to include ½ *rho* v^2 to represent kinetic energy.

Daniel, at age 30, had discovered his greatest contribution to science and engineering and confided this news to his good friend and colleague, Euler. Euler was a great favorite of Daniel's father who described him as the "*most learned and gifted man of science, Leonhard, Euler*". After seven years at the Academy, Daniel assembled a large volume of his work for publication and entrusted the manuscript to Euler and requested that Empress Catherine I name Euler his successor as professor of mathematics.

In 1732, he returned to the University of Basel, where he successively held the chairs of medicine, metaphysics and natural philosophy. In 1734, both he and his father were selected as co-winners, each their second award, in the French Academy competition. His father was not happy that his son was being so successful. Johann, unable to bear the "shame" of being compared as Daniel's equal, banned Daniel from his house.

At the end of this year, Daniel completed his manuscript and arranged for it to be printed in Strasbourg, France. It took more than 3 years for the type to be set and printed and was printed in 1738 as *Hydrodynamique* (*Hydrodynamica*),, by Daniel Bernoulli, Son of Johann. It has been compared to Joseph Louis Lagrange's *Mécanique Analytique* in being arranged so that all the results are consequences of a single principle, namely, conservation of energy.

He sent copies to Euler in St. Petersburg that were claimed to not have arrived for 3 years, that is, in 1740. In the meantime, Euler informed Daniel that his father's manuscript, titled *Hydraulics*, had reached him a year earlier claiming the results of original research on moving fluids! Three years later, in 1743, his father's book was published as *Hydraulics* and the publisher was instructed to print the year "1732" on the title page to make it appear to have been written earlier than his sons.

Daniel complained to Euler, "*What my father does not claim completely for himself he condemns,…and finally, at the height of my misfortune, he inserts the letter of your Excellence in which you, too, diminish my inventions in a field of which I am fully the first, even the only, author."*

In May, 1750 he was elected a Fellow of the Royal Society, but, he was so despondent that he decided to quite mathematics, stating: *"I would rather have learned the shoemaker's trade than mathematics"*. Like the unfortunate debate about the invention of the calculus, the debate about the conservation of energy in fluids highlights some of the ethical issues involved in science and engineering today. Daniel continued teaching medicine until his death on 8 March 1782.

His chief work was published in 1738. In 1733, the Industrial Revolution had started when John Kay invented the flying shuttle to speed up the weaving process. In 1765, James Hargraves had invented a machine that could spin eight strands of cotton at once. The United States of America declared independence from England in 1776 and in 1787, the Rev. Edmund Cartwright invented the power loom and a new force was being recognized, the force of electricity and magnetism. The world would never be the same.

Michael Faraday (1791-1867 CE)

Faraday was born on 22 September, 1791, nine years after Daniel Bernulli's death, in Newington Butts, now part of the London Borough of Southwark, one mile south of London Bridge. His family was not well off. His father, James, was a member of a *"very small and despised sect of Christians known, if known at all, as Sandemanians*". James Faraday moved his wife and two children to London during the winter of 1791 from Outhgill in Westmorland, where he had been an apprentice to the village blacksmith. Michael was born the autumn of that year. The young Michael Faraday, the third of four children Check???, having only the most basic of school educations, had to largely educate himself. *"My education",* Faraday would later lament, "*was of the most ordinary description, consisting of little more than the rudiments of reading, writing, and arithmetic at a common day school….My hours out of school were spent in the streets"*. During these years, the Faradays lived on nothing more than several loaves of bread a week – a dole from the English government. By age 13, Michael Faraday was little more than a poor, ignorant street urchin of London.

In 1804, England was at war with the new French leader, Napoleon Bonaparte, an imperialistic general who designed to conquer the world with the aid of the new and deadly machines spawned by the Industrial Revolution. Bonaparte was attracting talented young scientists and engineers from all over the world to Paris. Americans, who had recently won their independence from England, sent many, such as Robert Fulton who was designing steam-powered boats on the river Seine.

At fourteen Michael became apprenticed to a local bookbinder and bookseller George Riebau in Blandford Street. During his seven-year apprenticeship, he read many books, including Isaac Watts' *The Improvement of the Mind*, and he enthusiastically implemented the principles and suggestions that it contained. In particular, he was inspired by the book *Conversations on Chemistry* by Jane Marcet. While binding a copy of the *Encyclopaedia Britannica*, he learned from the 127 page entry how little was still known about electricity and magnetism (it was not even known that they were related).

It was only in 1785, that the French Charles-Augstin Coulomb had first observed the inverse square relationship of the magnetic repulsion force. He also observed that the same rule applied to electrically charged objects. Unlike mechanical forces, electric and magnetic forces were more of a mystery than an engineering tool at the beginning of the 19^{th} century.

At the age of twenty one, in 1812, at the end of his apprenticeship, Faraday attended lectures by the eminent English chemist Humphry Davy of the Royal Institution and Royal Society, and John Tatum, founder of the City Philosophical Society. Many tickets for these lectures were given to Faraday by William Dance (one of the founders of the Royal Philharmonic Society). Afterwards, Faraday sent Davy a three hundred page book based on notes taken during the lectures. Davy's reply was immediate, kind, and favorable. When Davy damaged his eyesight in an accident with nitrogen trichloride, he decided to employ Faraday as a secretary. When John Payne, one of the Royal Institution's assistants, was sacked, Sir Humphry Davy was asked to find a replacement. He appointed Faraday as Chemical Assistant at the Royal Institution on 1 March 1813.

In the class-based English society of the time, Faraday was not considered a gentleman. When Davy went on a long tour to the continent in 1813–15, his valet did not wish to go. Faraday was going as Davy's scientific assistant, and was asked to act as Davy's valet until a replacement could be found in Paris. Faraday was forced to fill the role of valet as well as assistant throughout the trip. Davy's wife, Jane Apreece, refused to treat Faraday as an equal (making him travel outside the coach, eat with the servants, etc.) and generally made Faraday so miserable that he contemplated returning to England alone and giving up science altogether.

The trip did, however, give him access to the European scientific elite and a host of stimulating ideas. It was on this tour that Faraday met Alessandro Volts, inventor of the battery, and Andre-Marie Ampere. Michael wrote "*I have learned just enough to perceive my ignorance, and, ashamed of my defects in everything, I wish to seize the opportunity of remedying them…The glorious opportunity of improving in the knowledge of chemistry and the sciences continually determines me to finish this voyage with Sir Humphry Davy".* By the time he returned to London, Michael had accumulated the equivalent of an upper-class education. Davy rewarded Michael with the dual promotion to the position of Superintendent of the Apparatus and as Assistant in the Laboratory and Mineral Collection. Like Leonardo da Vinci, Michael Faraday was largely self-taught. Unlike Leonardo, however, he published and his first technical paper in 1816 was on the "Analysis of Native Caustic Lime of Tuscany" in the *Quarterly Journal of Science*. Documentation and archiving technical details had become very important by the 19th century.

Faraday was a devout Christian. His Sandemanian denomination was an offshoot of the Church of Scotland. Well after his marriage, he served as Deacon and two terms as an Elder in the meeting house of his youth. Faraday married Sarah Barnard (1800–1879), the daughter of a silversmith, on 12 June 1821. They had no children. They met through their families at the Sandemanian church. He confessed his faith to the Sandemanian congregation the month after he married.

In 1820, soon after the Danish physicist and chemist, Hans Christian Ørsted discovered the phenomenon of electromagnetism, Davy and British scientist William Hyde Wollaston tried but failed to design an electric motor. After Michael's wedding he read and collated a large body of historical research on electricity and magnetism. He published this history with the unnoticed observation that electric and magnetic forces seemed to have a consistent orthogonal vector relationship in the *Annals of Philosophy*.

Faraday, having discussed the problem with Davy and Wollaston, went on to build two devices to produce what he called electromagnetic rotation: a continuous circular motion from the circular magnetic force around a wire and a wire extending into a pool of mercury with a magnet placed inside that would rotate around the magnet if supplied with current from a chemical battery. The latter device is known as a homopolar motor. These experiments and inventions form the foundation of modern electromagnetic technology. In his excitement, Faraday published results in October 1821 in the *Quarterly Journal of Science* "On Some New Electromagnetic Motions" without acknowledging his work with either Wollaston or Davy. The resulting controversy within the Royal Society strained his mentor relationship with Davy and may well have contributed to Faraday's assignment to other activities, thereby removing him from electromagnetic research for several years. Faraday responded to Wollaston regarding these accusations*:*

"I am bold enough Sir, to beg the favor of a few minutes' conversation with you on this subject, simply for these reasons-that I can clear myself- that I am anxious to escape from unfounded impressions against me- and if I have done any wrong that I may apologize for it."

Within two days, Wollaston assured everyone that his conversation did not constitute a plagiarism claim. Davy was silent on the point.

In 1824, Michael Faraday, self educated and son of a blacksmith, was nominated for membership in the Royal Society. Davy, as president of the society, campaigned against his nomination. Faraday wrote; ***"I replied [to Davy] that I was sure Sir H. Davy would do what he thought was for the good of the Royal Society*"**. Once again, the ethical issue of plagiarism rears its ugly head. On July 8, 1824, Faraday was voted membership with a Davy abstention. The following year he was promoted to director of the Royal Institution, within 12 years of his entry as a servant. It was his personal desire to learn, access to books, knowledge of the experimental method and access to an experimental laboratory that allowed faraday to make his contributions to engineering.

From his initial electromagnetic (EM) discovery in 1821, Faraday continued his laboratory work exploring properties of materials and developing the requisite experience. In 1824, Faraday briefly set up a circuit to study whether a magnetic field could regulate the flow of a current in an adjacent wire, but could find no such relationship. This lab followed similar work with light and magnets three years earlier with identical results. Two years after the death of Davy, in 1831, he began his great series of experiments in which he discovered electromagnetic induction. At about the same time, in 1826, a German school teacher, George Simon Ohm (1787-1854) announced the fundamental relationship between current, voltage and resistance that we refer to as Ohm's Law:

Current = Voltage / Resistance

Faraday's breakthrough in understanding Induction came on 29 August, 1831 when he wrapped two insulated coils of wire around an iron ring, and found that, upon passing a current through one coil, a momentary current was induced in the other coil. This phenomenon is known as mutual induction. The iron ring-coil apparatus is still on display at the Royal Institution. In subsequent experiments, he found that, if he moved a magnet through a loop of wire, an electric current flowed in the wire. The current also flowed if the loop was moved over a stationary magnet. His demonstrations established that a changing magnetic field produces an electric field. The 40 year old Faraday was unschooled in the language of mathematics and described his historic discovery in a single statement:

"Whenever a magnetic force increases or decreases, it produces electricity; the faster it increases or decreases, the more electricity it produces"

This relation was later modeled mathematically by James Clerk Maxwell as Faraday's law, which subsequently became one of the four Maxwell equations. These in turn have evolved into the generalization known today as field theory. Faraday later used the principle to construct the electric dynamo, the ancestor of modern power generators.

In June 1832, the University of Oxford granted Faraday a Doctor of Civil Law degree (honorary). 1833 he was appointed Fullerian Professor of Chemistry in the institution for life, without the obligation to deliver lectures**.** In 1839, he completed a series of experiments aimed at investigating the fundamental nature of electricity. Faraday used "static", batteries, and "animal electricity" to produce the phenomena of electrostatic attraction, electrolysis, magnetism, etc. He concluded that, contrary to scientific opinion of the time, the divisions between the various "kinds" of electricity were illusory. Faraday instead proposed that only a single "electricity" exists, and the changing values of quantity and intensity (current and voltage) would produce different groups of phenomena.

Near the end of his career, Faraday proposed that electromagnetic forces extended into the empty space around the conductor. This idea was rejected by his fellow scientists, and Faraday did not live to see this idea eventually accepted. Faraday's concept of lines of flux emanating from charged bodies and magnets provided a way to visualize electric and magnetic fields. That mental model of a “force field” was crucial to the successful development of electromechanical devices that dominated engineering and industry for the remainder of the 19th century.

During his lifetime, Faraday rejected a knighthood and twice refused to become President of the Royal Society. Faraday was elected a foreign member of the Royal Swedish Academy of Sciences in 1838, and was one of eight foreign members elected to the French Academy of Sciences in 1844. In 1848, as a result of representations by the Prince Consort, Michael Faraday was awarded a grace and favor in the house in Hampton Court, Surrey free of all expenses or upkeep. This was the Master Mason's House, later called Faraday House, and now No.37 Hampton Court Road. When asked by the British government to advice on the production of chemical weapons for use in the Crimean War (1853–1856), Faraday refused to participate citing ethical reasons.

In 1844, the telegraph began operation as a direct result of the knowledge of electromagnetism and will be discussed in more detail in chapter XX. In 1858 Faraday retired to live and die at his house at Hampton Court on 25 August 1867 aged 75 years and 11 months. He had previously turned down burial in Westminster Abbey, but he has a memorial plaque there, near Isaac Newton's tomb. Faraday was interred in the dissenters' (non-Anglican) section of Highgate Cemetery. Like Leonardo da Vinci, Michael Faraday was self-educated and superb at observation and recording the results of experiments and observations. It now was the time for a superb mathematician to use the power of the new calculus to expand on these observations.

James Clerk Maxwell (1831-1879)

The same year as Faraday’s famous experiment, James Clerk Maxwell was born, 13 June 1831 at 14 India Street, Edinburgh Scotland, to John Clerk, an advocate, and Frances Cay. Maxwell's father was a man of comfortable means, of the Clerk family of Penicuik, Midlothian, holders of the baronetcy of Clerk of Penicuik; his brother being the 6th Baronet. He had been born John Clerk, adding the surname Maxwell to his own after he inherited a country estate in Middlebie, Kirkcudbrightshire from connections to the Maxwell family, themselves members of the peerage.

Maxwell's parents did not meet and marry until they were well into their thirties, which was unusual for the time; moreover, his mother was nearly 40 years old when James was born. They had one earlier child, a daughter, Elizabeth, who died in infancy. They named their only surviving child James, a name that had sufficed not only for his grandfather, but also many of his other ancestors. He was an evangelical Presbyterian, and in his later years became an Elder of the Church of Scotland, Attending both Church of Scotland (his father's denomination) and Episcopalian (his mother's denomination) services as a child.

When Maxwell was young his family moved to Glenlair House, which his parents had built on the 1500 acre (6.1 km^2) Middlebie estate. All indications suggest that Maxwell had maintained an unquenchable curiosity from an early age. By the age of three, everything that moved, shone, or made a noise drew the question: "*what's the go o' that?"*. In a passage added to a letter from his father to his sister-in-law Jane Cay in 1834, his mother described this innate sense of inquisitiveness:

"*He is a very happy man, and has improved much since the weather got moderate; he has great work with doors, locks, keys, etc., and "show me how it doos" is never out of his mouth. He also investigates the hidden course of streams and bell-wires, the way the water gets from the pond through the wall..."*

Recognizing the potential of the young boy, his mother Frances took responsibility for James' early education, which in the Victorian era was largely the job of the woman of the house. She was however taken ill with abdominal cancer, and after an unsuccessful operation, died in December 1839 when Maxwell was only eight. James' education was then overseen by John Maxwell and his sister-in-law Jane, both of whom played pivotal roles in the life of Maxwell. His formal schooling began unsuccessfully under the guidance of a sixteen-year-old hired tutor. Little is known about the young man John Maxwell hired to instruct his son, except that he treated the younger boy harshly, chiding him for being slow and wayward. John Maxwell dismissed the tutor in November 1841, and after considerable thought, sent James to the prestigious Edinburgh Academy. He lodged during term times at the house of his aunt Isabella. During this time his passion for drawing was encouraged by his older cousin Jemima, who was herself a talented artist.

The ten-year-old Maxwell, having been raised in isolation on his father's countryside estate, did not fit in well at school. The first year had been full, obliging him to join the second year with classmates a year his senior. His mannerisms and Galloway accent struck the other boys as rustic, and his having arrived on his first day of school wearing a pair of homemade shoes and a tunic, earned him the unkind nickname of "Daftie. Maxwell, however, never seemed to have resented the epithet, bearing it without complaint for many years. Social isolation at the Academy ended when he met Lewis Campbell and Peter Guthrie Tait, two boys of a similar age who were to become notable scholars later in life. They would remain lifetime friends.

Maxwell was fascinated by geometry at an early age, rediscovering the regular polyhedron before any formal instruction. Much of his talent however, went overlooked, and despite winning the school's scripture biography prize in his second year his academic work remained unnoticed until, at the age of 13, he won the school's mathematical medal and first prize for both English and poetry.

Maxwell wrote his first scientific paper at the age of 14. In it he described a mechanical means of drawing mathematical curves with a piece of twine, and the properties of ellipses, Cartesian ovals, and related curves with more than two foci. His work, *Oval Curves*, was presented to the Royal Society of Edinburgh by James Forbes, who was a professor of natural philosophy at Edinburgh University. Maxwell was deemed too young for the work presented. The work was not entirely original, since Descartes had also examined the properties of such multifocal curves in the seventeenth century, but Maxwell had simplified their construction.

Maxwell left the Academy in 1847 at the age of 16 and began attending classes at the University of Edinburgh. Having had the opportunity to attend the University of Cambridge after his first term, Maxwell instead decided to complete the full course of his undergraduate studies at Edinburgh. The academic staff of Edinburgh University included some highly regarded names, and Maxwell's first year tutors included Sir William Hamilton, who lectured him on logic and metaphysics, Philip Kelland on mathematics, and James Forbes on natural philosophy. Maxwell, however, did not find his classes at Edinburgh University very demanding, and was therefore able to immerse himself in private study during free time at the university, and particularly when back home at Glenlair. There he would experiment with improvised chemical, electric, and magnetic apparatuses, but his chief concerns regarded the properties of polarized light. He constructed shaped blocks of gelatin, subjected them to various stresses, and with a pair of polarizing prisms given to him by the famous scientist William Nicol he would view the colored fringes which had developed within the jelly. Through this practice Maxwell discovered photo elasticity, which is a means of determining the stress distribution within physical structures.

Maxwell contributed two papers for the Transactions of the Royal Society of Edinburgh at the age of 18. One of these, *On the equilibrium of elastic solids*, laid the foundation for an important discovery later in his life, which was the temporary double refraction produced in viscous liquids by shear stress. His other paper was titled *Rolling curves*, and just as with the paper *Oval Curves* that he had written at the Edinburgh Academy, Maxwell was again considered too young to stand at the rostrum and present it himself. The paper was delivered to the Royal Society by his tutor Kelland instead.

In October 1850, already an accomplished mathematician, Maxwell left Scotland for Cambridge University. He initially attended Peterhouse, but before the end of his first term transferred to Trinity College, where he believed it would be easier to obtain a fellowship. At Trinity, he was elected to the elite secret society known as the Cambridge Apostles. In November 1851, Maxwell studied under William Hopkins, whose success in nurturing mathematical genius had earned him the nickname of "senior wrangler-maker". A considerable part of Maxwell's translation of his equations regarding electromagnetism was accomplished during his time at Trinity.

In 1854, Maxwell graduated from Trinity with a degree in mathematics. He scored second highest in the final examination, coming behind Edward Routh, and thereby earning himself the title of Second Wrangler. He was later declared equal with Routh, however, in the more exacting ordeal of the Smith's Prize examination. Immediately after earning his degree, Maxwell read a novel paper to the Cambridge Philosophical Society entitled *On the transformation of surfaces by bending*. This is one of the few purely mathematical papers he had written, and it demonstrated Maxwell's growing stature as a mathematician. Maxwell decided to remain at Trinity after graduating and applied for a fellowship, which was a process that he could expect to take a couple of years. Buoyed by his success as a research student, he would be free, aside from some tutoring and examining duties, to pursue scientific interests at his own leisure.

The nature and perception of color was one such interest, and had begun at Edinburgh University while he was a student of Forbes. Maxwell took the colored spinning tops invented by Forbes, and was able to demonstrate that white light would result from a mixture of red, green and blue light. His paper, *Experiments on color,* laid out the principles of color combination, and was presented to the Royal Society of Edinburgh in March 1855. Fortunately for Maxwell this time it would be he himself who delivered his lecture.

Maxwell was made a fellow of Trinity on 10 October 1855, sooner than was the norm, and was asked to prepare lectures on hydrostatics and optics, and to set examination papers. However, the following February he was urged by Forbes to apply for the newly vacant Chair of Natural Philosophy at Marischal College, Aberdeen. His father assisted him in the task of preparing the necessary references, but he would die on 2 April, at Glenlair before either knew the result of Maxwell's candidacy. Maxwell nevertheless accepted the professorship at Aberdeen, leaving Cambridge in November 1856.

The 25-year-old Maxwell was a decade and a half younger than any other professor at Marischal, but engaged himself with his new responsibilities as head of department, devising the syllabus and preparing lectures. He committed himself to lecturing 15 hours a week, including a weekly *pro bono* lecture to the local working men's college. He lived in Aberdeen during the six months of the academic year, and spent the summers at Glenlair, which he had inherited from his father.

His mind was focused on a problem that had eluded scientists for two hundred years: the nature of Saturn's rings. It was unknown how they could remain stable without breaking up, drifting away or crashing into Saturn. The problem took on a particular resonance at this time as St John's College; Cambridge had chosen it as the topic for the 1857 Adams Prize. Maxwell devoted two years to studying the problem, proving that a regular solid ring could not be stable, and a fluid ring would be forced by wave action to break up into blobs. Since neither was observed, Maxwell concluded that the rings must comprise numerous small particles he called "brick-bats", each independently orbiting Saturn. Maxwell was awarded the £130 Adams Prize in 1859 for his essay *On the stability of Saturn's rings*; he was the only entrant to have made enough headway to submit an entry. His work was so detailed and convincing that when George Biddell Airy read it he commented *"It is one of the most remarkable applications of mathematics to physics that I have ever seen*." It was considered the final word on the issue until direct observations by the *Voyager* flybys of the 1980s confirmed Maxwell's prediction. Maxwell would also go on to disprove mathematically the nebular hypothesis (which stated that the solar system formed through the progressive condensation of a purely gaseous nebula), forcing the theory to account for additional portions of small solid particles.

In 1857 Maxwell befriended the Reverend Daniel Dewar, who was the Principal of Marischal, and through him met Dewar's daughter, Katherine Mary Dewar. They were engaged in February 1858 and married in Aberdeen on 2 June 1859. Comparatively little is known of Katherine, seven years Maxwell's senior. Maxwell's biographer and friend Campbell adopted an uncharacteristic reticence on the subject, though describing their married life as "*one of unexampled devotion*".

In 1860, Marischal College merged with the neighboring King's College to form the University of Aberdeen. There was no room for two professors of Natural Philosophy, and Maxwell, despite his scientific reputation, found himself laid off. He was unsuccessful in applying for Forbes' recently vacated chair at Edinburgh, the post instead going to Tait. Maxwell was granted the Chair of Natural Philosophy at King's College London instead. After recovering from a near-fatal bout of smallpox in the summer of 1860, Maxwell headed south to London with his wife Katherine.

Maxwell's time at King's was probably the most productive of his career. He was awarded the Royal Society's Rumford Medal in 1860 for his work on color, and was later elected to the Society in 1861. This period of his life would see him display the world's first light-fast color photograph, further develop his ideas on the viscosity of gases, and propose a system of defining physical quantities—now known as dimensional analysis. Maxwell would often attend lectures at the Royal Institution, where he came into regular contact with Michael Faraday. The relationship between the two men could not be described as close, as Faraday was 40 years Maxwell's senior and showed signs of senility. They nevertheless maintained a strong respect for each other's talents.

This time is especially known for the advances Maxwell made in the fields of electricity and magnetism. He had examined the nature of both electric and magnetic fields in his two-part paper *On physical lines of force*, published in 1861, in which he had provided a conceptual model for electromagnetic induction, consisting of tiny spinning cells of magnetic flux. Two more parts later added to the paper were published in early 1862. In the first of these he discussed the nature of electrostatics and displacement current. The final part dealt with the rotation of the plane of polarization of light in a magnetic field, a phenomenon discovered by Faraday and now known as the Faraday Effect.

In 1865, Maxwell resigned the chair at King's College London and returned to Glenlair with Katherine. He wrote a textbook entitled *Theory of Heat* (1871), and an elementary treatise, *Matter and Motion* (1876). Maxwell was also the first to make explicit use of dimensional analysis, in 1871.

It was also in the year 1871 that he became the first Cavendish Professor of Physics at Cambridge. Maxwell was put in charge of the development of the Cavendish Laboratory. He supervised every step in the design of the building and of the purchase of the very valuable collection of apparatus paid for by its generous founder, the 7th Duke of Devonshire (chancellor of the university, and one of its most distinguished alumni). One of Maxwell's last great contributions to science and engineering was the editing (with copious original notes) of the electrical researches of Henry Cavendish, from which it appeared that Cavendish researched, amongst other things, such questions as the mean density of the earth and the composition of water.

Maxwell had studied and commented on the field of electricity and magnetism as early as 1855/6 when "*On Faraday's lines of force*" was read to the Cambridge Philosophical Society. The paper presented a simplified model of Faraday's work, and how the two phenomena were related. He reduced all of the current knowledge into a linked set of differential equations with 20 equations in 20 variables. This work was later published as "*On physical lines of force*" in March 1861.

Around 1862, while lecturing at King's College, Maxwell calculated that the speed of propagation of an electromagnetic field is approximately that of the speed of light. He considered this to be more than just a coincidence, and commented "*We can scarcely avoid the conclusion that light consists in the transverse undulations of the same medium which is the cause of electric and magnetic phenomena*."

Working on the problem further, Maxwell showed that the equations predict the existence of waves of oscillating electric and magnetic fields that travel through empty space at a speed that could be predicted from simple electrical experiments; using the data available at the time, Maxwell obtained a velocity of 310,740,000 m/s. In his 1864 paper "A dynamical theory of the electromagnetic field", Maxwell wrote:

"*The agreement of the results seems to show that light and magnetism are affections of the same substance, and that light is an electromagnetic disturbance propagated through the field according to electromagnetic laws*".

Maxwell was proven correct, and his quantitative connection between light and electromagnetism is considered one of the great accomplishments of 19th century mathematical physics.

His famous equations, in their modern form of four partial differential equations, first appeared in fully developed form in his textbook *A Treatise on Electricity and Magnetism* in 1873. Most of this work was done by Maxwell at Glenlair during the period between holding his London post and his taking up the Cavendish chair. Maxwell expressed electromagnetism in the algebra of quaternions and made the electromagnetic potential the centerpiece of his theory. In 1881 Oliver Heaviside replaced Maxwell’s electromagnetic potential field by ‘force fields’ as the centerpiece of electromagnetic theory. Heaviside reduced the complexity of Maxwell’s theory down to four differential equations, known now collectively as Maxwell's Laws or Maxwell's equations. In simplified vector differential equation form for a vacuum in space they can be written as the wave equations where E is the electric field, B is the magnetic field and c is the speed of light.

$$\nabla \cdot \mathbf{E} = 0$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}.$$

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}.$$

Maxwell also introduced the concept of the *electromagnetic field* in comparison to force lines that Faraday discovered. By understanding the propagation of electromagnetism as a field emitted by active particles, Maxwell could advance his work on light. At that time, Maxwell believed that the propagation of light required a medium for the waves, dubbed the luminiferous aether. Over time, the existence of such a medium, permeating all space and yet apparently undetectable by mechanical means, proved more and more difficult to reconcile with experiments such as the Michelson–Morley experiment. Moreover, it seemed to require an absolute frame of reference in which the equations were valid, with the distasteful result that the equations changed form for a moving observer. These difficulties inspired Albert Einstein to formulate the theory of special relativity, and in the process Einstein dispensed with the requirement of a luminiferous aether.

Maxwell published a famous paper "On governors" in the *Proceedings of Royal Society*, vol. 16 (1867–1868). This paper is quite frequently considered a classical paper of the early days of control theory. Here governors refer to the governor or the centrifugal governor used in steam engines. As the steam engine was one of the driving forces in the Industrial revolution, understanding the theoretical underpinnings of heat engines became a major engineering issue of the 19^{th} century.

One of Maxwell's major investigations was on the kinetic theory of gases. Originating with Daniel Bernoulli, this theory was advanced by the successive research of Rudolf Clausius. In 1866, he formulated statistically, independently of Ludwig Boltzmann, the Maxwell–Boltzmann kinetic theory of gases. His formula, called the Maxwell distribution, gives the fraction of gas molecules moving at a specified velocity at any given temperature. In the kinetic theory, temperatures and heat involve only molecular movement. This approach generalized the previously established laws of thermodynamics and explained existing observations and experiments in a better way than had been achieved previously. Maxwell's work on thermodynamics led him to devise the *Gedankenexperiment* (thought experiment) that came to be known as Maxwell's demon.

In 1871, he established Maxwell's thermodynamic relations, which are statements of equality among the second derivatives of the thermodynamic potential with respect to different thermodynamic variables. In 1874, he constructed a plaster thermodynamic visualization as a way of exploring phase transitions, based on the American scientist Josiah Willard Gibbs's graphical thermodynamics papers.

He died in Cambridge of abdominal cancer on 5 November 1879 at the age of 48. His mother had died at the same age of the same type of cancer. Maxwell is buried at Parton Kirk, near Castle Douglas in Galloway, Scotland.

The practical development of the steam engine by Newcomen and Watt in 1769 (22 years before the birth of Faraday and 62 years before the birth of Maxwell) led to the requirement to develop a new field of engineering called thermodynamics. The first law of this new field was an extension of the Conservation of Energy laws developed by Leibnitz (for solids) and Bernoulli (for fluids) to heat engines.

Maxwell was an early contributor to the development and theoretical understanding of this new field that was to become central to the field of mechanical engineering. Steam engines were still very inefficient, however, and Sadi Carnot and Rudolf Clausius did much to help understand what determines this inefficiency by developing the 2nd Law of Thermodynamics.

Rudolf Julius Emanuel Clausius (1822-1888)

In 1822, Lazare Carnot's son, Sadi Carnot (1796-1832), published his famous *Reflections on the Motive Force of Heat.* Sadi's father, Lazare had been Napoleon I's minister of war and his engineer son, Sadi, was depressed that France was in a state of decline after her defeat led by England. The English steam engine was one of the reasons for the growth in England's industrial power and they produced more work (Force X Distance) for a given amount of fuel (or heat energy) than the French steam engines. Sadi developed the mathematical concept of a perfect (or ideal) heat engine that converts heat energy into work energy and found that there was a maximum theoretical efficiency dictated by only the maximum and minimum absolute temperatures available to the ideal, reversible closed system. This efficiency is defined as:

Carnot efficiency = 1 – Low Absolute Temperature/High Absolute Temperature

Carnot calculated that an engine whose boiler and radiator temperatures were 160 and 40 degrees Celsius, respectively, should theoretically produce 20 billion foot-pounds of work for every ton of coal it burned. When he compared the actual output of the best English engines of the time, he found that even the best produced less than 5 percent of the theoretical output. In 1832, Sadi contracted cholera and died at the age of 36. Unfortunately, the perfect theoretical engine envisioned by Carnot could never exist because real engines have losses.

The same year Carnot published his paper, Rudolf Clausius was born on 2 January, 1822 the son of Ernst Carl Gottlieb Clausius, a protestant minister in Koslin, Prussia (now Koszalin, Poland). Ernst moved to Uckermunde on the coast of Pomeranian Bay of the Baltic Sea to start a new one-room private school which Rudolf and his brothers and sisters studied. After completion of his high school education in the nearby port city of Stettin, the 18 year old Rudolf entered the University of Berlin in 1840, as five of his brothers had done before him. By the time he completed his undergraduate studies in 1844, he had developed a deep interest in the nature of heat. It was just a year earlier that he was to learn that his mother had died giving birth to her eighteenth child. In addition to helping raise his younger siblings, he entered the University of Halle, about 100 miles southwest of Berlin. In addition to studying for his doctorate, Clausius was working as a high school teacher and caring for four of his younger siblings. In 1848, he completed his doctorate and continued teaching high school while he searched for a university teaching position. Clausius was particularly interested in Carnot's observation that heat engines were the reverse of nature's friction. Heat engines turned heat into work while natural friction turned work into heat.

His most famous paper, "*Über die bewegende Kraft der Wärme*" ("*On the Moving Force of Heat and the Laws of Heat which may be Deduced Therefrom*") was published in 1850, and dealt with the mechanical theory of heat. In this paper, he showed that there was a contradiction between Carnot's principle and the concept of conservation of energy. Clausius restated the two laws of thermodynamics to overcome this contradiction. In this paper, he argued that heat and work were fundamentally the same thing, energy, and that the total energy of the universe was conserved. This came to be known as the Law of Energy Conservation.

The net change in the total energy of the universe is zero

The first law of thermodynamics can also be expressed by the fundamental thermodynamic relation:

> ***For a thermodynamic cycle, the net heat supplied to the system equals the net work done by the system.***

At the age of thirty two, Clausius was finally offered a professorship at the new but prestigious university in Zurich, Switzerland, the *Ecole Polytechnium*. He next became professor of physics at the Royal Artillery and Engineering School in Berlin and Privatdozent at the Berlin University. In 1855 he became professor at the ETH Zürich, the Swiss Federal Institute of Technology in Zürich, where he stayed until 1867. On 13 November 1859, he met and wed the German woman named Adelheid Rimpau. In 1867, he moved to Würzburg and two years later, in 1869 to Bonn.

Professionally, Clausius had observed that there were now many forms of energy recognized: solar, mechanical, electrical, acoustic, etc. Before leaving Zurich in 1865, he postulated that all of these forms of energy were a manifestation of the same thing, which he called *entropy*. Entropy, he imagined, encompassed not only all the varieties of energy but also temperature, which could be measured directly. He believed that energy changes and temperature changes could be measured against a common ruler. He decided on a sign convention that all natural increases in energy would be counted as *Positive*. That is whenever a cup of coffee cooled or a warm house lost heat to the colder outside, the entropy at those locations was INCREASING, because this was the natural flow of energy. Conversely, whenever an unnatural energy change occurred, like changing heat into work, the entropy was DECREASING. As he considered the ideal heat engines of Carnot, he found that there was no net change in entropy for those ideal closed systems.

When he applied his bookkeeping to real steam engines, he found that the natural entropy always increased, that is entropy was not conserved in the real world but was increasing. This became accepted and known as the Second Law of thermodynamics:

The net change in the total entropy of the universe is always greater than zero

The implications of this law are many and profound. It says that the universe is a heat engine that is running down and will eventually reach zero motion at absolute zero. It has been used in information theory to describe the decay in signal or information integrity. Later, Boltzman was to prove mathematically that entropy is a measure of *disorganization*.

In 1870 Clausius organized an ambulance corps in the Franco-Prussian War. He was wounded in battle, leaving him with a lasting disability. He was awarded the Iron Cross for his services. His wife, Adelheid Rimpham, died in childbirth in 1875, leaving him to raise their six children. He continued to teach, but had less time for research thereafter. In 1886 he remarried Sophie Sack, and then had another child. Two years later, on 24 August 1888, he died in Bonn, Germany. Our understanding of the nature of the universe would never be the same.

The Laws that govern the majority of our technical advancement by engineers in the 20th century were now in place. In 1876, Nikolaus Otto announces his invention of the first internal combustion engine and in 1892, Rudolf Diesel patents his improved efficiency engine in Germany. Between 1880 and 1900, hydroelectric plants began to spring up in industrial centers of both Europe and America. In 1896, Charles G. Curtis (1860-1953), patented the first steam turbine designed to produce electricity. By 1903, the first steam generated electric power plant was in operation in Newport RI, USA to power the Newport & Fall River Street Railway Company with 500 thousand watts of power. A modern steam-electric power plant today operates at about 30 to 40% thermal efficiency. A very large, high efficiency Diesel engine may be able to approach 50%. The efficiency of power generation and it's mobility and energy density are critical engineering problems to be solved as we enter the 21st century.

The 20th Century and Grand challenges for the Future

The 20th century saw the building of giant skyscrapers, hydroelectric dams and electric power networks, automobiles, interstate highway land transportation networks, jet airplanes that can circumnavigate the globe in a day, time and position measurement to nanoseconds and meters of accuracy, rockets that can travel to the moon, submarines that can cruise the world's oceans for months at a time, high-bandwidth wireless communications and a ubiquitous world-wide internet system. Unfortunately, our energy use has significantly increased the amount of carbon dioxide that enters the atmosphere. This is happening at a time when our climate was already undergoing a periodic increase in temperature. We now know that our planet is fundamentally a heat engine with a molten iron core that produces our protective magnetic field from the sun's cosmic rays. Between our own internal heat engine and the sun's irradiative heat energy, the twin fluid layers over our spherical earth are governed by the Navier Stokes equations. These equations are a combination of the vector Conservation of Mass, Conservation of Momentum, Conservation of Energy, thermodynamic equations of state and shear stress equations of water and air. The solutions of these equations tell us what the future weather and climate will be. They are formally chaotic in nature and not easy to solve, even with the best computers we have today. The equations need empirical data as inputs to the boundary conditions. New remote sensing satellite and ocean monitoring systems need to be developed to provide this synoptic data.

As we enter the 21st century, we are faced with the problems of better understanding of our climate, increased energy efficiency, cyber warfare, information management, air/land network expansion and traffic control, travel to the planets of our solar system, elimination of water pollution and many more. These problems will be solved by our future engineers. It will take a tremendous amount of knowledge and hard work but our civilizations' future will depend on how well we perform as a profession.

Chapter Timeline

287 BCE Archimedes born

218-201 BCE 2nd Punic War between Rome and Carthage

212 BCE Archimedes dies having founded *statics* and *hydrostatics*

90 BCE Vitruvius architect and civil engineer of Rome born

20 BCE Vitruvius dies

476 Western Roman Empire ends

~500 Chinese and Arabic science and mathematics becomes organized

1389-1464 Cosimo de Medici in Florence

1449-92 Lorenzo de Medici in Florence

1452 Leonardo da Vinci born near Florence

1455 Gutenberg printing press starts in Germany

1519 Leonardo dies in France having observed the Continuity Relationship for Fluids

1627 Robert Boyle born in Ireland

1642 Isaac Newton born in England

1646 Gottfried Leibniz born in Leipzig, Saxony

1662 Royal Society founded in England

1666 French Academy of Sciences founded by King Louis XIV

1684 Leibniz publishes calculus

1687 Newton publishes Principia using calculus

1691 Robert Boyle dies

1695 Leibniz publishes Conservation of mechanical energy "*vis vita*"

1700 Daniel Bernulli born in Netherlands

1711 Newton accuses Leibniz of plagerism

1716 Leibniz dies in disgrace

1727 Newton dies and is buried at Westminster

1734 Daniel and his father Johann Bernuilli share French Academy prize

1736 James Watt born in Glasgow Scotland

1738 Daniel Bernuilli publishes Hyrodynamique and Conservation of energy for fluids

1742 Johann Bernuilli publishes Hydraulics, backdated to "1732"

1742 Edmund Cartwright born Nottinghamshire, England

1750 Daniel Bernuilli elected Fellow of the Royal Society

1782 Daniel Bernuilli dies in Basel

1785 Cartwright patents power loom

1788 Watt patents Steam Engine with condenser

1791 Michael Faraday born in England

1796 Sadi Carnot born in France

1815 Napoleon I defeated at Waterloo

1819 James Watt dies Birmingham, England

1821 Michael Faraday publishes first paper on EM theory

1822 Rudolf Clausius born in Prussia

1823 Edmund Cartwright dies Sussex, England

1822 Sadi publishes Reflections on the Motive Force of Heat

1824 Michael Faraday elected to Royal Society

1826 Georg Simon Ohm (1787-1854) announces Ohm's law

1831 Michael Faraday publishes paper on Mutual Induction

1831 James Clerk Maxwell born in Scotland

1832 Sadi Carnot dies of Cholera

1861 Maxwell elected to Royal Society

1861 Maxwell publishes first field theory paper

1865 Clausius publishes 1st and 2nd Law of Thermodynamics and entropy in Zurich, Switzerland

1867 Michael Faraday dies at Hampton Court, England

1868 Clausius elected to Royal Society

1870 Franco Prussian War

1871 Maxwell publishes Theory of Heat

1873 Maxwell publishes “Maxwell Equations”

1876 Nikolaus Otto announces development of the Internal Combustion engine

1879 Maxwell dies at Cambridge, England

1888 Clausius dies in Bonn, Germany

1892 Rudolf Diesel (1858-1913) patents more efficient IC engine in Germany

1896 Charles G. Curtis patents a steam turbine for electricity production

1903 first commercial steam electric power plant for Newport & Fall River St. railway Co.

Discussion Questions

1. **How many of these men were involved with medical research? Compare and contrast their involvements.**
2. **Compare and contrast the ethical issues raised by charges of plagiarism highlighted in these case studies.**
3. **Why were there not any women included in these case studies?**
4. **Compare and contrast the educational backgrounds.**
5. **How many of these individuals conducted their own experimental research?**
6. **How many of these individuals carried their designs to practice?**
7. **Expand on the lives of any of these individuals.**

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