

**Development of Electrical Engineering**

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## **Abstract**

The basic stages of electrical engineering throughout history. Key people and their respective inventions that contribute to the field of electrical engineering are reviewed. Mainly focused on the beginning of electricity and magnetic fields starting from the 1620s with the invention of Gilbert's versorium to the late theoretical discoveries of the 20th century, including invention of the light bulb and the principles of television. Fundamental energy laws and publications of key scientists are also considered.

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## Introduction

The first publication that really started the cycle of discoveries in electrical engineering was written by William Gilbert in England in the exact year of 1600. “On the Magnet and Magnetic Bodies, and on the Great Magnet, the Earth” which was the first paper to define to some extent what electrostatics are, the definition of a static charge and the first step into a deep field of electromagnetics and definition of magnetic fields [1]. We start our discussion at this man and will move in cycles throughout history observing four generations of development. It is important to point out that not all discoveries can be covered but the analysis that has been performed suggests these key events, people and their respective inventions hold enough knowledge to get an understanding of electrical engineering’s history.

Although electrical engineering was not offered as a university degree until the late nineteenth century, the works of numerous scientists laid the foundation that the profession is built on today. It was Sir Isaac Newton who once said “If I have seen further it is by standing on the shoulders of giants.” With each scientist and inventor in the field building on the work and discoveries of the preceding scientists, this quote holds true for many contributors to the development of electrical engineering as well. Whether it was Andre-Marie Ampere building on the work of Hans Christian Orsted, Michael Faraday building on the work of Ampere, or James Maxwell building on the contributions of Faraday in the 1800’s, the field of electrical engineering would not be as it is today without these scientists standing on the shoulders of the ones that came before.

Following Gilbert’s definition of electromagnetic forces, Charles Coulomb formulated his law regarding the electric force between two charges and continued the work on electrostatics in the eighteenth century. Coulomb’s law is arguably the breakthrough of the century because of its incredible impact on the electrical engineering that is studied and practiced today.

Although significant breakthroughs in electrostatics began in the seventeenth and eighteenth centuries, it was in the nineteenth century that the study of electricity intensified immensely. The nineteenth century includes the birth of electrodynamics, the invention of the electric battery, and groundbreaking discoveries and inventions. All courtesy of the brilliant minds of Alessandro Volta, Georg Simon Ohm, Gustav Kirchhoff, and Nikola Tesla. In fact, it was in the late nineteenth century that electrical engineering began to be offered as a university degree. [4]

The twentieth century covers a few inventions, for the purpose of this report we are going to 1920s only. Electrical engineering from 1900 to 1920s takes us to the invention of the fluorescent lamp, the diode, the triode, radio technology and the laid out principles of television. [7]

## **Discussion**

## Development in the 17th Century

### William Gilbert

Electricity has been a subject of interest in the early 17th century, although no definition has been asserted to electricity. An early scientist William Gilbert first drew a distinction between magnetism and static electricity and is the man credited with establishing the definition of electricity. [1] His research has been proved by his invention of the Versorium, an instrument that detects electrical charge.

### Versorium

The invention seen on Figure 1 is a needle constructed out of metal which is able to pivot on a pedestal. It is very similar to compass needle but unmagnetized [2]. The needle is attracted to charged bodies and brought near it, will turn towards the charged object [2]. Versorium can distinguish between charged and uncharged objects. Very similar to a magnetic compass, but influenced by electrostatic forces rather than magnetic forces. The differences between these two different forces were poorly understood and Gilbert performed a series of experiments to prove their separatism which is one of the reasons he was given credit as the first father of electrical engineering.



Versorium de Gilbert.

*Figure 1: Gilbert's Illustration of Versorium*

## Development in the 18th Century

### Coulomb's Law

One of the most significant contributions to the development of electrical engineering in the eighteenth century was the development of Coulomb's law by French physicist Charles-Augustine De Coulomb in 1783. Coulomb's work on electrostatics is still relevant, institutions study and practice Coulomb's work and have developed further understanding of E.G. His law describes the force interacting between static electric charges and is still taught in all introductory physics courses. Coulomb's law states that the electric force between two charges is directly proportional to the product of the magnitude of the charges,

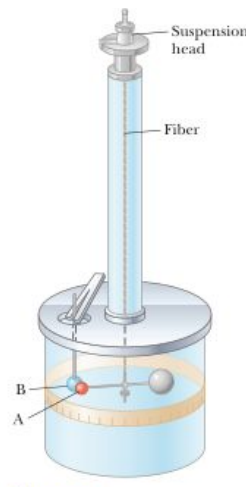
and inversely proportional to the square of the distance between them. The mathematical representation of the law is shown below:

$$F_e = \frac{k(q_1 q_2)}{r^2}$$

Where  $k$  is known as Coulomb's constant and has a value of  $8.99 \times 10^9$  with units of  $\frac{Nm^2}{C^2}$ . Coulomb's constant can also be written in the following form

$$k_e = \frac{1}{4\pi\epsilon_0}$$

Where the value  $\epsilon_0$  is the permittivity of free space and has a value of  $8.85 \times 10^{-12}$ . The charges  $q_1$  and  $q_2$  are measured in Coulombs, which is the SI unit of charge named in Charles Coulomb's honour. Coulomb came upon his discovery through experiments with what is known as a torsion balance. A diagram of the apparatus is shown in Figure 2. Coulomb's torsion balance consists of a glass case at the bottom closed by a lid. A glass tube emerges from the lid, which is then closed with a suspension head. A torsion fiber which holds a horizontal needle is suspended from the suspension head.



*Figure 2: Coulomb's Apparatus*

The discoveries and inventions made by Coulomb in the eighteenth century were huge breakthroughs in the field of physics and electrical engineering. Coulomb's law provided scientist with a tool for calculating the net electric force between two charges, and the law has the following properties: Like charges repel each other and unlike charges attract, and the attraction or repulsion acts along the line between the two charges. Coulomb's law would also go on to be an incredibly useful tool for physicists

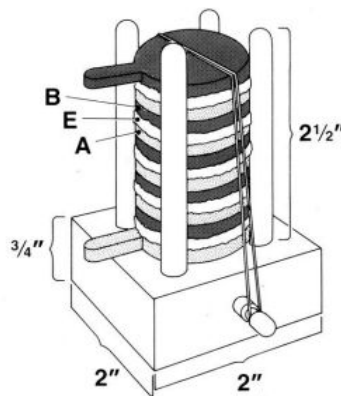
## Development in the 19th Century

The nineteenth century is arguably the most significant period when it comes to the development of electrical engineering. Some of the most fundamental laws in the field of electrical engineering were developed during this cycle. By the later part of the century, numerous scientists and inventors helped shape the world we live in today. The scientists and inventors that made major contributions to the discoveries and inventions of the nineteenth century include the likes of Alessandro Volta, Georg Simon Ohm, and Gustav Kirchhoff.

### Alessandro Volta

When it comes to the development of electrical engineering, the nineteenth century got off to a great start right away with the invention of the first electric battery in the year 1800. Italian physicist Alessandro Volta had experimented with electricity for many years in the late eighteenth century, however it was not until 1800 that Volta provided the first source of continuous current.

Known as the voltaic pile, the first electric battery was a groundbreaking discovery. Volta put together a pile of alternating metal disks, separated by what is now known as electrolytes. The pile built by Volta consisted of zinc and silver disks. There was a steady current produced when a wire was connected to both ends of the pile and the field of electrodynamics was born [4]. Volta discovered that the amount of current produced varied depending on the different types of metal used in the pile [4]. He also found that the more disks added to the stack resulted in a greater current. The invention of the electric battery helped many other scientists discover even more groundbreaking results in the field.



*Figure 3: Voltaic Pile*

The apparatus of Volta's battery is shown above in Figure 3. "A" and "B" are metals, and "E" is an electrolyte layer. The unit volts (V) used to measure the potential difference across an element is named after Alessandro Volta. Thanks to Alessandro Volta, for the first time ever scientists could produce a steady electric current.

## Georg Simon Ohm & Ohm's Law

Discovered in 1827 by German physicist Georg Simon Ohm, Ohm's law may be the most fundamental law in all of electrical engineering. Ohm realized that the voltage across most materials is directly proportional to the current through the material. Georg Simon Ohm published his work in 1827 and stated Ohm's law in the following mathematical representation:

$$V = IR$$

As simple as that mathematical relationship between current and voltage is, it is that equation which is used today in almost any electrical circuit analysis by electrical engineers. The variable  $V$  represents the voltage applied across the material. Voltage is also known as the potential difference and is measured in units of volts (V). It is a measurement of how much energy is required per unit charge. Therefore, one volt is equal to one joule (J) per coulomb (C).

$$1V = 1 \frac{J}{C}$$

The variable  $I$  represents the current through the material, measured in units of amperes (A). The current is a measurement of the rate at which the charge passes a fixed point. Therefore, one ampere (A) is equal to one coulomb (C) per second (s), mathematically written as

$$1A = 1 \frac{C}{s}$$

Finally, the variable  $R$  represents the resistance of the material, measured in units of ohm's ( $\Omega$ ) in honour of Georg Simon Ohm. Resistance is the physical property of an element or device that impedes or resists the flow of current. The unit of resistance is equal to one volt per ampere. The mathematical representation is

$$1\Omega = 1 \frac{V}{A}$$

Although Ohm's law is taught today in virtually any introductory physics or engineering textbook, it was not an easy road for Ohm to prove his discovery. Ohm's work was ridiculed by physicists at the time and received no credit for his work.

## Kirchhoff's Laws

Ohm's law provides electrical engineers of today with a basic mathematical tool for analyzing electric circuits. In 1845, another German physicist by the name of Gustav Kirchhoff experimentally determined two more laws that would greatly simplify electric circuit analysis, Kirchhoff's current law (KCL) and Kirchhoff's voltage law (KVL).

KCL states that the algebraic sum of all the currents at any node in a circuit must equal 0. In other words, all of the current entering a node must be equal to all of the current that is exiting that node. KVL states that the algebraic sum of the voltages around a closed loop in a circuit is equal to zero for all time. Like Ohm's law, these two laws developed by Kirchhoff are so fundamental to electrical engineering that they are taught in virtually all introductory textbooks today.



For a better visualization, consider the following example of Kirchhoff's current law in Figure 4. The current  $I_1$  is entering a node that branches off in two directions. Ultimately  $I_1$  will split into two different currents labelled as  $I_2$  and  $I_3$ . This is written mathematically as:

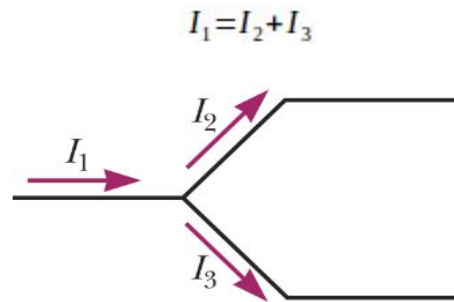


Figure 4: Kirchhoff's Law Demonstration

For an example of KVL applied in a problem, consider the circuit shown in Figure 5. As shown in the circuit, the current  $I$  is going in a clockwise direction. The direction of the current is the analyzer's choice but it will change the signs in your equation depending on the direction you choose. So whichever direction that is chosen, make sure it is consistent with the equation. As the current travels in a clockwise direction, the voltage drops and voltage rises of each element is put into the equation. For resistors, use Ohm's law to express the voltage in terms of the current and the resistance. The equation derived from completing a KVL in this circuit is:

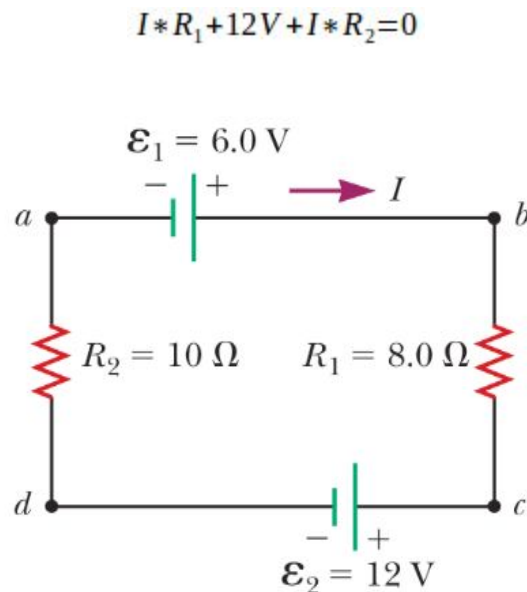


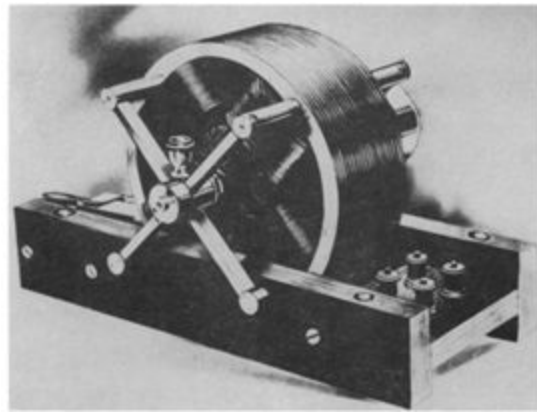
Figure 5: KVL Application In Circuit Theory

Kirchhoff's rules are just as fundamental to circuit analysis as Ohm's law is. Without these laws, circuit analysis would be much more difficult and who knows what electrical engineering would be like today.

### Nikola Tesla

Nikola Tesla's invention of the induction motor in 1887 forever revolutionized the world. It is the brilliance of Nikola Tesla that allows us to enjoy the electric lighting in our homes and buildings the way that we do today.

The induction motor invented by Tesla made it possible to transmit power over much greater distances by means of alternating current [5]. This ability to transmit power over greater distances meant less power stations were needed to be built, compared to direct current power stations. However, Tesla's former employer, Thomas Edison did not make it easy for Tesla to demonstrate the usefulness of his invention. As an advocate for the use of direct current over alternating current, Thomas Edison went to extreme lengths to prove Tesla's invention was a safety hazard. After receiving investments from George Westinghouse, Tesla's invention ultimately prevailed. The induction motor is shown in Figure 6, taken from [10].



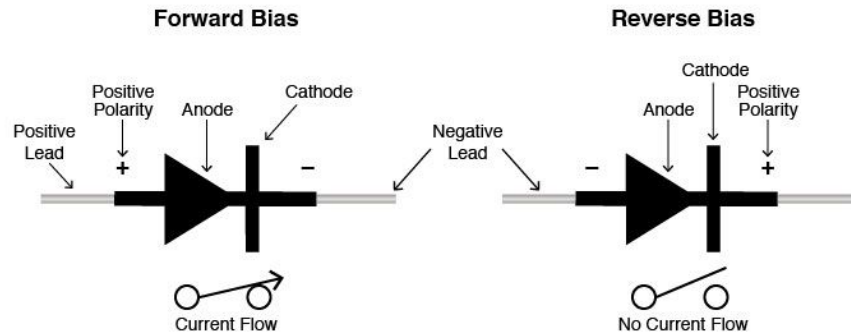
*Figure 6: Tesla's Induction Motor*

### **Development in the Early 20th Century**

Italian inventor Guglielmo Marconi performed the first radio broadcast in 1900. A year later, American engineer Peter Hewitt invented the Fluorescent lamp. [2]

John Fleming invented the first radio tube, the diode, in 1904. [1]

The common function of a diode is to allow an electric current to pass in one direction while blocking current in the opposite direction. This unidirectional behavior is called rectification, and is used to convert alternating current (AC) to direct current (DC), including extraction of modulation from radio signals in radio receivers—these diodes are forms of rectifiers.



*Figure 7: Forward and Reverse Direction of Electric Current in Diode*

Diodes can have more complicated behavior than (on or off) state, because of their nonlinear current-voltage characteristics. Semiconductor diodes begin conducting electricity only if a certain threshold voltage or cut-in voltage is present in the forward direction. [3] The voltage drop across a forward-biased diode varies only a little with the current, and is a function of temperature; this effect can be used as a temperature sensor or as a voltage reference. [3]

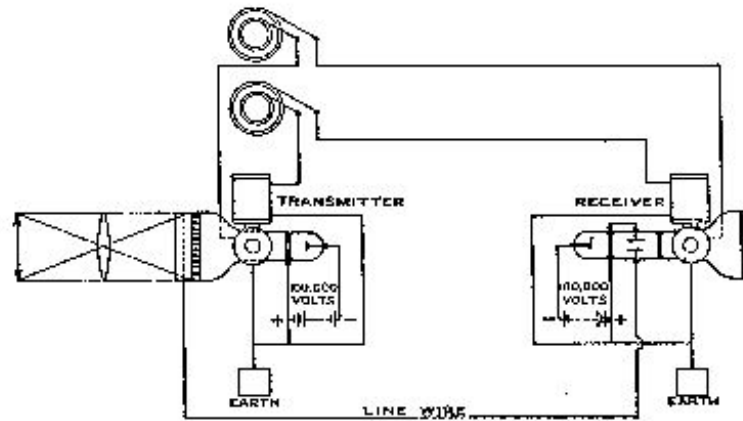
2 years later, Lee de Forest succeeded in implementing a triode. Its invention founded the electronics age, making amplified radio technology and long-distance telephony possible. [2]

In 1908, Scottish engineer Alan Archibald Campbell-Swinton, laid the principles of Television.

### The Principles of Television

Campbell-Swinton is the first man to envision a completely electronic television system. He first described an electronic basis of producing television in a 1908. In the letter, Swinton described a design using cathode-ray tubes to both capture the light and display the image. [10]

Basic cathode-ray tubes at this time had been invented, and much similar to today, they were relatively large vacuum tubes with a long neck on one end and a flat screen on the other. An electron gun in the neck could shoot a stream of electrons toward the flat end of the tube which was covered with an internal coating of light-emitting phosphor. [10]



*Figure 8: Scheme of Swinton's Idea*

Swinton reasoned the electron stream will push back and forth in rows from top to bottom while varying the intensity of the electron stream, a moving image could be drawn in the same manner as with Nipkow's disks.

### **Conclusion**

The foundations laid out by William Gilbert have started a cycle of innovation in the four generations that were reviewed. The first man to define electricity and observe the distinction between electrostatic forces and magnetism.

The eighteenth century had a major groundbreaking discovery made by the French physicist Charles-Augustin de Coulomb. Coulomb's experiments and inventions allowed him to develop Coulomb's law, which is one of the most significant principles of electrical engineering today. Coulomb's law provided scientists and engineers with a basic tool that could not only calculate the electric force between two charged particles, but also calculate electric fields. The reason we discuss Coulomb's law is because it is arguably the greatest discovery in the field of electrostatics.

The nineteenth century is by far the most significant century when it comes to the development of electrical engineering. Numerous scientists and inventors, including ones not mentioned in this report made incredible advances that ultimately lead to the world we live in today. With the genius of Alessandro Volta, scientists gained a new way to study electricity, known as electrodynamics. Volta's invention of the electric battery paved the path for future scientists and engineers who improved the design and turned it into one of the most useful creations in the world.

Later in the century, Georg Simon Ohm and Gustav Kirchhoff developed the most fundamental laws in all of electrical engineering. Nikola Tesla's invention revolutionized the way that power is distributed to homes and commercial buildings and is what provides with the lighting we receive today. All of these great scientists and inventors changed electrical engineering forever, and we are the beneficiaries of these all-time great scientific breakthroughs and inventions.

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Figure 1: Illustration taken from: <https://www-spf.gsfc.nasa.gov/earthmag/NSTA1B.htm>

Figure 2-6: Illustrations taken from [9]

Figure 7,8: Illustrations taken from [10]