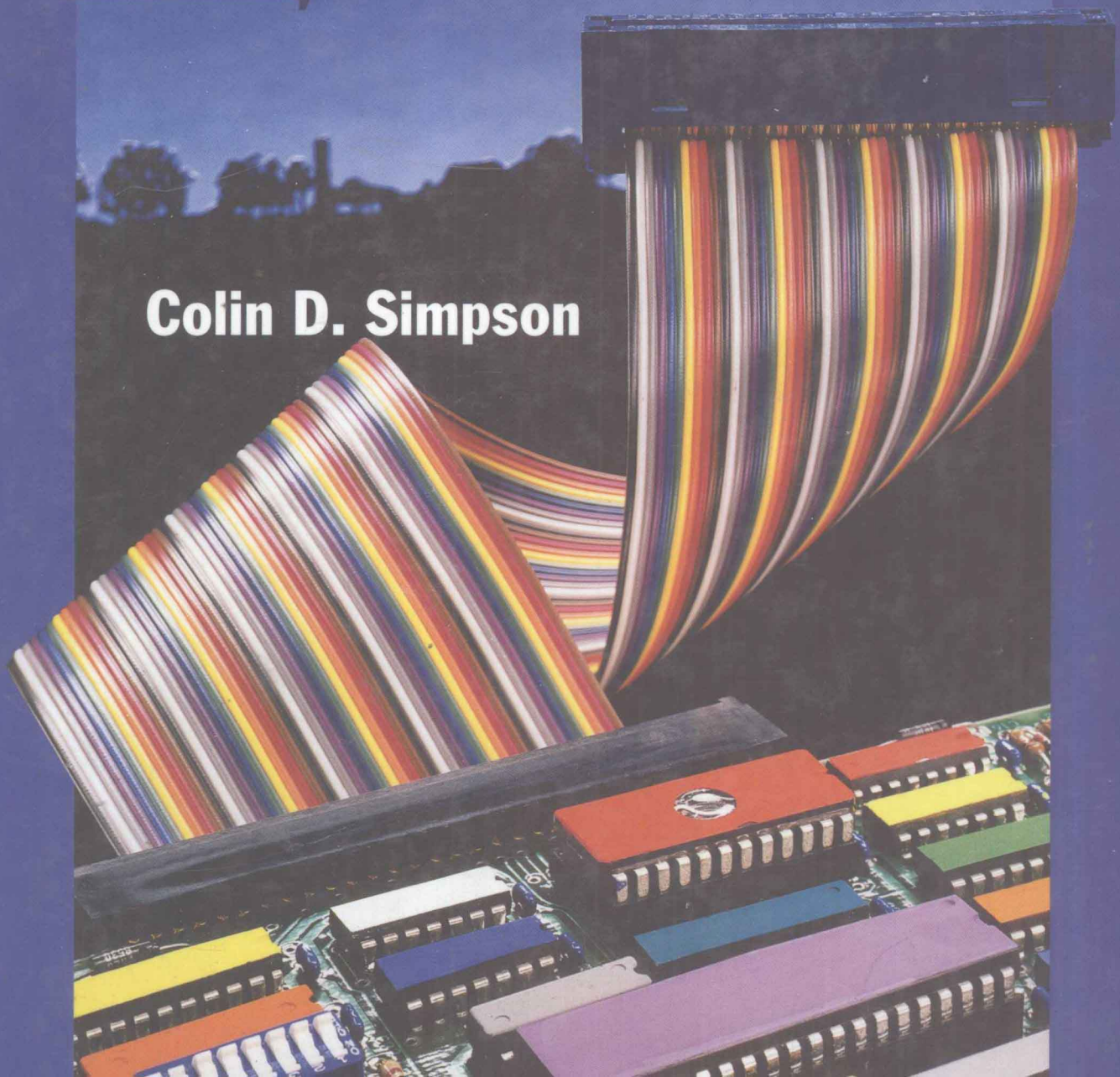
PRINCIPLES OF ELECTRONICS

Colin D. Simpson



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PREFACE

Principles of Electronics has been written primarily for use in electronic engineering technician and technology programs. The content is suitable for community colleges and technical institutes. The topics follow a typical sequence for two- and four-year electronics courses. For each subject, the basic principles are explained first, followed by applications and troubleshooting techniques. Students using this book should have an understanding of algebra up to quadratic equations and of trigonometry up to the simple properties of triangles. The availability of a scientific calculator is assumed. The calculator must handle trigonometric and exponential functions as a minimum. Basic principles, theorems, circuit behavior, and problem-solving procedures are presented so that the average student can get a clear understanding of essential concepts. The large number of example problems and exercises should make this book useful for self-study and review, and should serve as preparation for more advanced courses.

The introductory chapters cover essential concepts of electricity, including atomic structure, electric charges, Ohm's law, Kirchhoff's laws, energy, and power. Early in the book introductory circuit analysis techniques are emphasized to assist the student in developing an approach to solving problems related to electronic circuits. Thévenin's theorem, the superposition theorem, and the maximum power transfer theorem are covered in early chapters. In addition to electric circuit analysis, the book also covers topics such as magnetism, resonance, filters, semiconductor diodes, transistors, and electronic circuits. Electron current flow is used throughout the text, and, in accordance with the Institute of Electrical and Electronic Engineers (IEEE), the SI system of measurement is used wherever practical.

My primary objective in writing this book was to take what many perceive to be a difficult subject and make it easier to understand. In my experience, I have found that many students have difficulty grasping the basic principles of electronic circuits and that the most effective method of teaching these principles is to present them in a relatively nonmathematical format. Over the years, I have developed a method of teaching electronics that is straightforward and uses a minimum of mathematical equations. This is not to say that the depth or complexity of the subject matter has been sacrificed. It simply means that the book is more readable. Concepts are reinforced with practical applications as well as mathematical solutions. If the student can relate the circuit or device to a real-world application, the learning curve improves dramatically.

Every effort has been made to achieve accuracy and clarity throughout the text. Having written three books on the subject of electricity and electronics, I was able to apply many of the lessons learned from previous publications. I was also able to utilize a database of several hundred professors who have taught electronics to obtain their opinions on course content, depth of material, chapter organization, and accuracy. As always, I welcome all praise and criticism from students, professors, and people in industry. As an author, feedback from users of my books is tremendously helpful. Please feel free to write to me c/o George Brown College, P.O. Box 1015 Station B, Toronto, Ontario, Canada, M5T 2T9. My Internet address is csimpson@gbrownc.on.ca.

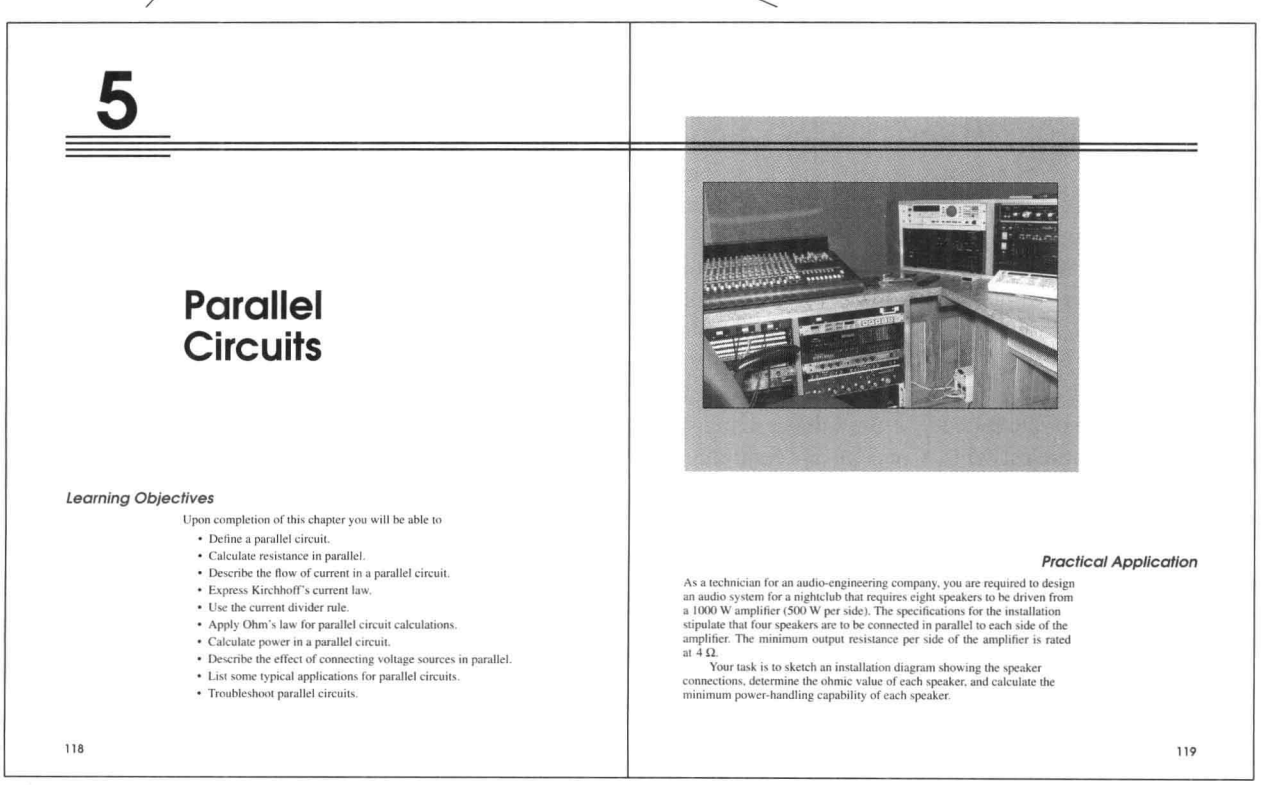
Features of the Book

Each chapter contains numerous features that are designed to aid in the learning process and to reinforce key concepts and applications for the chapter topics.

- Learning objectives at the beginning of each chapter specify the chapter's goals.
- A practical application task is also introduced at the beginning of each chapter, and the final section provides a solution.
- Hundreds of worked examples throughout the text illustrate fundamental concepts.
- Review questions at the end of each section provide an immediate self-check of key concepts and principles, with answers given at the end of the chapter.
- A detailed summary at the end of each chapter emphasizes the important concepts covered in the chapter.
- The end-of-chapter problems test learning of chapter concepts and reinforce problem-solving skills.
- A comprehensive glossary at the end of the book serves as easy-to-use reference source for students.

The two-page chapter opener lists the chapter's learning objectives on the left page.

The right page of the chapter opener introduces a practical application task that is solved in the final section of the chapter.



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Parallel Circuits

Learning Objectives

Upon completion of this chapter you will be able to

- Define a parallel circuit.
- Calculate resistance in parallel.
- Describe the flow of current in a parallel circuit.
- Express Kirchhoff's current law.
- Use the current divider rule.
- Apply Ohm's law for parallel circuit calculations.
- Calculate power in a parallel circuit.
- Describe the effect of connecting voltage sources in parallel.
- List some typical applications for parallel circuits.
- Troubleshoot parallel circuits.

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Practical Application

As a technician for an audio-engineering company, you are required to design an audio system for a nightclub that requires eight speakers to be driven from a 1000 W amplifier (500 W per side). The specifications for the installation stipulate that four speakers are to be connected in parallel to each side of the amplifier. The minimum output resistance per side of the amplifier is rated at 4 Ω.

Your task is to sketch an installation diagram showing the speaker connections, determine the ohmic value of each speaker, and calculate the minimum power-handling capability of each speaker.

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Hundreds of worked examples appear throughout the text.

Section review questions provide an immediate self-check at the end of each section.

The final section in each chapter provides a detailed solution for the practical application task introduced in the chapter opening.

A chapter summary that highlights key points and the answers to section reviews appear at the end of every chapter.

The back-of-book glossary provides easy access to key terms and definitions.

EXAMPLE 6–19

Calculate the voltages across R_1 and R_2 for the circuit of Figure 6–37(b).

Solution The total resistance of the circuit with R_1 opened consists of R_2 and R_3.

$$R_T = R_2 + R_3 = 18.2\ \Omega + 200\ \Omega$$

The voltage drops can now be found using the voltage divider rule

$$V_{R2} = \left(\frac{R_2}{R_T}\right)E_T = \left(\frac{18.2\ \Omega}{218.2\ \Omega}\right)20\ \text{V} = 1.67\ \text{V}$$

$$V_{R3} = \left(\frac{R_3}{R_T}\right)E_T = \left(\frac{200\ \Omega}{218.2\ \Omega}\right)20\ \text{V} = 18.33\ \text{V}$$

Section Review

1. What happens to a series-parallel circuit when a short occurs in one of the components?
2. Why is it more difficult to provide overcurrent protection for a series-parallel circuit than a parallel circuit?
3. When an open-circuit condition occurs in a series-parallel circuit, the voltage drops in the circuit remain constant (True/False).

6–10 PRACTICAL APPLICATION SOLUTION

The design requirements for a dual-polarity power supply were outlined in the chapter opener. Your task was to design a power supply capable of supplying 200 mA for a +10 V and −10 V load. The following steps illustrate the method of solution for this practical application of series-parallel circuits.

STEP 1 Sketch a wiring diagram showing the reference point for the dual polarity supply (Figure 6–38). Three resistors are required for the circuit. Because the source is 24 V and the total voltage requirements are 20 V, a series-dropping resistor (R_1) must drop the difference (4 V). The other two resistors (R_2 and R_3) form a divider to provide the +10 V and −10 V values. The two load resistors are connected with R_2 and R_3 at the reference, or ground, point for the circuit.

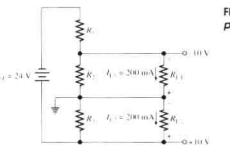

FIGURE 6–38 *Circuit for practical application.*

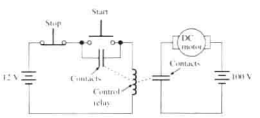

FIGURE 9–10 *Diagram of stop/start circuit with control relay.*

was to energize and de-energize the DC motor. The following steps demonstrate the method of solution for this practical application of magnetism.

STEP 1 Draw a diagram of how the circuit is to be connected. Figure 9–10 shows a diagram of the low-voltage control circuit and high-voltage power circuit. The dashed lines between the windings of the electromagnet and contacts indicate that the electromagnet controls these contacts. When the start button is pressed, the contact in parallel with the start button closes and the contact in series with the DC motor and 100 V supply also closes. The relay remains energized after the start button is released because a path for the current is provided through the parallel contact. Because the stop button is in series with the start button and holding contact, when the stop button is pressed, current flow is interrupted to the electromagnetic coil and the contacts return to their normally open state.

STEP 2 Test the circuit. Thoroughly check the wiring for the circuit and verify that the installation is complete before starting the motor.

Summary

1. A moving electron carries a negative electrical charge. The spinning effect of the electron creates a magnetic field.
2. The total number of lines of force in a given region is called *magnetic flux*.
3. The attraction or repulsion between magnets varies directly with the product of their strengths and inversely with the square of the distance between them.
4. When a material is easy to magnetize, it is said to have a *high permeability*.
5. When an electric current is passed through a long straight conductor, a magnetic field is established in and around the conductor.
6. The magnetic field around a current-carrying conductor can be intensified by forming the conductor into a coil, or solenoid.
7. Solenoids are electromagnetic devices with a moveable iron core.
8. Relays are electromagnetic devices that use one or more sets of contacts to make or break control circuits.
9. Permanent magnets are often used with electromagnets in audio and video devices for the recording and playback of signals.
10. The Hall effect is based on the Hall voltage, which is a voltage developed across a magnetic field.

Answers to Section Reviews

Section 9–1

1. False
2. That the earth is a huge magnet with its magnetic north pole near the geographical north pole and the magnetic south pole located near the geographical south pole
3. The presence of iron

GLOSSARY

Absolute permittivity (ε) The flux produced with a vacuum as dielectric; also known as absolute capacitivity.

AC resistance The effective resistance of a conductor; includes factors such as skin effect and radiation loss.

Active device A device, such as a transistor, capable of controlling voltage or current.

Active filter A filter network that uses an active device to obtain the desired filtering effect.

Additive polarity A winding connection that causes the direction of counter emf in both windings to be the same.

Admittance (Y) The ease at which an AC current flows in a circuit; the reciprocal of impedance, measured in siemens (S).

Admittance triangle A right-angle triangle that relats conductance, susceptance, and admittance.

Air-core inductor An inductor that contains no magnetic iron and generally is wound on a tubular insulating material.

Air gap A part of the magnetic circuit of electromagnets, and used to increase reluctance.

Alternating current (AC) A current in which the magnitude and direction varies with time.

Alternating emf A voltage in which the magnitude and direction varies with time.

American Wire Gauge (AWG) A standard for manufacturing and numbering wires.

Ammeter A measuring instrument used to indicate electrical current in amperes.

Ampere (A) The SI base unit of electric current; the rate of electric charge flow when 1 C of charge passes a given point in 1 s.

Ampere's circuit law A law that states the algebraic sum of the rises and drops of the mmf around a closed loop of a magnetic circuit is equal to zero.

Amplitude The maximum positive or negative value of an alternating current, voltage, or power; also known as peak value.

Analog meter A moving-coil measuring instrument.

Angular velocity The rate of change of a quantity, such as voltage, in an ac circuit.

Apparent power The product of the total rms voltage and current in a circuit, expressed in volt-amperes (VA).

Arcing A phenomenon caused by interrupting current, such as opening a switch, that produces a very high induced voltage because of the rapidly collapsing field.

The supporting ancillary package for *Principles of Electronics* includes the following:

- Test item file
- Computerized test bank
- Transparency package with transparency masters
- Student study guide
- Instructor's manual
- Laboratory manual
- Video library
- Electronics workbench software
- Bulletin board in America Online

Organization of the Book

The book is divided into 23 chapters. The chapter opener provides an insight into a practical application of electronic technology. A particular task is outlined at the beginning of the chapter and the solution is presented in the final numbered section. The hundreds of worked examples and problems in this book have been selected and written to illustrate fundamental concepts essential to the troubleshooting and design of electronic circuits. To promote immediate reinforcement of problem-solving skills, section reviews are provided at the end of each major topic. The answers for the section reviews are included at the end of the chapter.

Chapter 1 presents an introduction to electronics, including applications, components, and the principles of electric charge. Chapters 2 and 3 provide information on the fundamentals of current, voltage and resistance, as well as Ohm's law, power, and energy. Chapters 4 through 6 describe series, parallel, and series-parallel circuits with an emphasis on troubleshooting and practical application. Troubleshooting is reinforced in Chapter 7 with a presentation of DC measuring instruments and practices.

A thorough discussion of DC network theorems is provided in Chapter 8, including Thévenin's theorem, Norton's theorem, and the maximum power transfer theorem. Chapters 9 and 10 describe the principles of magnetism and the magnetic circuit. Chapter 11 begins by introducing the phenomenon known as alternating current and ends with a discussion of nonsinusoidal waveforms and harmonic frequencies. Troubleshooting with AC meters is emphasized in Chapter 12 using equipment such as oscilloscopes, frequency counters, and signal generators.

The principles of capacitors and inductors are presented in Chapters 13 and 14. Chapter 15 describes the fundamentals of transformers including isolation transformers, multiple-winding transformers, transformer polarity, pulse transformers, and troubleshooting. Chapter 16 provides a comprehensive treatment of alternating current circuits and describes the effects of AC on resistors, inductors, and capacitors. Resonance in series and parallel circuits is discussed in Chapter 17, including selectivity, bandwidth, and resonant frequency. Chapter 18 describes the basics of coupling and filtering circuits with an emphasis on practical application.

Chapter 19 begins the final stage in the organization of the book. This chapter on semiconductor fundamentals provides the foundation for the subsequent chapters on transistors, thyristors, amplifiers, op-amps, and digital circuits. Chapter 20 presents a discussion on the basic operating principles of BJTs, FETs, SCRs, triacs, and UJTs. Amplifier cir-

cuits are described in Chapter 21 with an emphasis on practical applications. Chapter 22 introduces the op-amp, and Chapter 23 presents an overview of digital electronics.

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Principles of Electronics

1

Introduction

Learning Objectives

Upon completion of this chapter you will be able to

- Understand the historical perspective of electricity and electronics.
- Describe some of the important areas where electronics technology is applied.
- List examples of common electronic components.
- Define the basic units of measurement.
- Describe the SI system of measurement.
- Be able to express numbers in scientific notation.
- Convert from one power of 10 to another.
- Define engineering notation.
- Describe basic atomic structure.
- Explain the principle of electric charge.
- Express Coulomb's law.

Practical Application

Each chapter in this book begins with a practical application of electronics. The purpose of the practical application is to illustrate how the material covered in a particular chapter relates to situations you may encounter as an electronics technician. Because the field of electronics is so diverse, every effort has been made to present a wide cross section of the employment possibilities available and a brief overview of the tasks expected of you as a technician.

The practical applications presented at the beginning of each chapter outline a task you are expected to perform as an electronic technician for companies involved in the manufacture, design, installation, and maintenance of electronic equipment. When you have completed a chapter, your knowledge of the material covered in the chapter should be sufficient to solve the task described in the practical application. The last section in each chapter describes the method of solution for a given task.

1-1 HISTORY OF ELECTRICITY AND ELECTRONICS

In 600 B.C. the Greeks discovered that certain substances, when rubbed with fur, caused other substances to be attracted to them. Thales of Miletus (640 B.C.–546 B.C.) is credited with having been among the first to observe the attraction of amber for small fibrous materials and bits of straw. Amber, a solidified tree sap, was used by these people for ornamental purposes. The Greek word for amber was *elektron,* which is the root word for *electricity.*

Although the electrification of amber by friction was known for many centuries, it was not until the beginning of the seventeenth century that Sir William Gilbert (1544–1603) announced the discovery that many substances could be electrified by friction. In Gilbert's book *De Magnete,* he also described how amber differs from magnetic lodestones in its attraction of certain materials. Gilbert demonstrated that lodestone always attracts iron or other magnetic bodies, but an electric object exerts its attraction only when it has been recently rubbed.

It was Gilbert's discoveries that led scientists to the realization that all fundamental properties of electricity and magnetism can be traced to the state or motion of something called *electric charge.* In 1733, a Frenchman named Charles F. DuFay (1698–1739) made an important discovery while experimenting with the conduction of electricity. DuFay found that a glass rod became electrified when rubbed with silk and that a rod made of wax would become electrified when rubbed with fur. What made DuFay's discovery so significant was that he determined that the rods possessed two different kinds of electrical "fluid."

In the eighteenth century, Benjamin Franklin (1706–1790) introduced the terms *positive* (+) and *negative* (−) to describe the two types of electricity. Franklin defined a glass rod that had been rubbed with silk as having a positive charge and a wax or rubber rod rubbed with fur as having a negative charge.

In 1785, physicist Charles Augustin de Coulomb (1736–1806) proved the laws of attraction and repulsion that exist between positive and negative electric charges. **Coulomb's law** states that the force acting between two charges is directly proportional to the product of the two charges and inversely proportional to the square of the distances between the charges.

A year later, in 1786, the Italian scientist Luigi Galvani made a startling discovery during his experiments with electricity. Galvani found that a frog's leg could be made to twitch if copper and iron were brought into contact with a nerve and a muscle. Galvani named his discovery *animal electricity.*

In 1796, Alessandro Volta furthered Galvani's research by proving that electricity could be produced if unlike metals separated by moistened paper were brought into contact. In his original design Volta stacked pairs of unlike metals on top of each other in order to increase the intensity of the electric charge. This arrangement became known as the *voltaic pile,* which was the first battery.

The first significant connection between magnetism and electricity was uncovered by Hans Christian Oersted (1777–1851) in 1820. Oersted accidently discovered that a current-carrying wire influenced the orientation of a nearby compass needle. Oersted's discovery tied the origin of magnetic fields to the motion of electric charges and became known as *electromagnetism.*

In 1826 German physicist Georg Simon Ohm (1787–1854) observed that the electrical resistance of metallic conductors remains constant over wide ranges of potential difference. This observation became known as **Ohm's law.**

Two scientists are given credit for the discovery of **electromagnetic induction:** Michael Faraday (1791–1867) and Joseph Henry (1797–1878). Since Faraday was the first to publish his findings, the laws of electromagnetic induction are called **Faraday's laws.**

The dawn of electronics began in 1868 when Heinrich Geissler (1814–1879) developed "Geissler tubes," in which electrical discharges in rarefied gases produced different colors. These tubes, made in diverse sizes, shapes, and colors, attracted the attention of physicists in the leading scientific institutions and universities of the world.

One of the scientists intrigued by Geissler tubes was Sir William Crookes (1832–1919), an English physicist and chemist. Crookes is widely credited with being the inventor of the first cathode ray tube.

In 1883 Thomas Edison (1847–1931) made an interesting discovery during his work on the incandescent light bulb. When Edison inserted an electrode in a glass bulb with a filament, he found that a current would flow if a positive potential was applied to the electrode and the filament was hot. Edison also noted that no current would flow if the filament was cold. This device was the first thermionic diode and eventually led to the invention of the electronic vacuum tube.

Sir John Fleming recognized the importance of Edison's discovery, and in 1904 he developed the Fleming valve, which is now called a vacuum-tube rectifier, or diode. The Fleming valve is still used in some circuits, such as radio and television transmitters and receivers, to change alternating current into direct current.

The first vacuum tube capable of boosting, or amplifying, small electrical signals was patented in 1907 by Lee de Forest (1873–1961). The vacuum tube used by de Forest was a triode tube.

The first tetrode tube was invented by the German scientist Walter Schottky in 1916. Schottky is credited with a great many inventions during his career, among them the first semiconductor diode in 1938.

In 1947 three American scientists, John Bardeen, Walter Brattain, and William Shockly, invented the transistor. It was this discovery that ushered in the era of solid-state electronics.

In 1958 the integrated circuit (IC) was developed by Jean Hoerni, Jack Kilby, Kurt Lehovec, and Robert Noyce. The integrated circuit can now contain thousands of transistors on a semiconductor chip the size of a thumbnail.

The development of the IC led to the invention of the microprocessor by Ted Hoff in 1971. Hoff's discovery revolutionized the computer industry, greatly reducing the size and cost of computing machines.

In 1977 three companies, Apple, Radio Shack, and Commodore, introduced personal computers for home and office use. The development of personal computers was furthered by the Motorola Corporation in 1979 when it began marketing a powerful 16-bit microprocessor.

In 1980, Microsoft introduced the MS-DOS disk-operating system for personal computers, which evolved into an industry standard for computers using INTEL microprocessors. Further developments in microprocessor technology led to the development of the 64-bit, 100 MHz, Pentium microprocessor by INTEL, which was made commercially available in 1993.

Section Review

1. What laws did Charles Augustin de Coulomb prove in 1785?
2. Who was it that discovered "animal electricity"?
3. What device was invented in the 1970s that led to the development of the personal computer?

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