Practical Electricity

for Aviation Maintenance Technicians

based on the original text by Dale Crane

edited by Dennis W. Wilt

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Aviation Supplies & Academics, Inc.
Newcastle, Washington

Practical Electricity for Aviation Maintenance Technicians
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with technical editor Dennis W. Wilt

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Printed in the United States of America.

2020 2019 2018 2017 8 7 6 5 4 3 2 1

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ASA-PR-ELEC
ISBN 978-1-61954-347-8

Library of Congress Cataloging-in-Publication Data:

Names: Crane, Dale, author. | Wilt, Dennis W., editor.
Title: Practical electricity for aviation maintenance technicians / Dale Crane ; edited by Dennis W. Wilt.
Description: Newcastle, Washington : Aviation Supplies & Academics, Inc., [2017]
Identifiers: LCCN 2017016623| ISBN 9781619543478 (trade pbk. : alk. paper) | ISBN 1619543478 (trade pbk. : alk. paper)
Subjects: LCSH: Aviation mechanics (Persons)—Handbooks, manuals, etc. | Electricity—Study and teaching.
Classification: LCC TL671.9 .C668 2017 | DDC 629.135/4—dc23
LC record available at https://lccn.loc.gov/2017016623

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Preface

Aircraft electrical systems are no longer limited to the starter, generator, battery and ignition system, and the electronic system is no longer just the "radio." Modern aircraft are loaded with electric motors, lights, instruments and heaters, and the avionics and electronic controls have made flight profitable, safe, and efficient.

Aviation maintenance has been traditionally divided into two categories, airframe and powerplant, but now there is a third essential category; electrical systems. Even though the FAA has no separate rating for them, maintenance of the electrical and electronic systems is fully as vital and demanding as the engines and airframe systems.

Practical Electricity for Aviation Maintenance Technicians has been prepared as a classroom text for those preparing to enter the field of aviation maintenance as well as for experienced mechanics who want to increase their knowledge of electricity and electrical systems. It begins with a simple explanation of what electricity is and progresses through DC and AC circuit analysis to a practical description of airframe and powerplant electrical systems and an introduction to avionic systems and digital electronics. All of this is put together in a simple explanation of systematic troubleshooting of electrical systems.

Aviation Supplies & Academics, Inc. is dedicated to providing the aviation maintenance profession with materials needed to form a solid foundation for keeping up with this fast moving area of technology.

Dale Crane
1923–2010

Dennis W. Wilt

Dennis W. Wilt is the Chief Executive Officer, Aviation Consultant, and founder of Wilt Aviation Consulting, LLC. Mr. Wilt has a Bachelor's degree in Electrical Engineering from The University of Florida, as well as a Master's of Business Administration and a Master's of Science in Aviation—Aviation Safety from Florida Institute of Technology. He has been working in the aviation field for over 30 years. He has had a varied career as an engineer and engineering manager working for several major engineering firms. He has done everything from testing oil and gas wells on oil rigs offshore in Louisiana, to managing the program development and certification of the first radios on the Boeing 777. While working on the NASA Small Aircraft Transportation Systems program in the early 2000's, he assisted in the development of the very first synthetic vision systems used in general aviation.

Mr. Wilt has been a pilot and aircraft owner since 1980. In 2011, he and his wife, Dr. Donna Wilt, completed building an Arion Lightning Experimental—Amateur Built aircraft. Mr. Wilt is a member of the Experimental Aircraft Association (EAA) and is the former president and current treasurer of EAA Chapter 1288. He is also a member of the Aircraft Owners and Pilots Association (AOPA), the AOPA Airport Service Network Volunteer for Sebastian Municipal Airport (X26) in Sebastian, FL, and a member of The Society of Aviation and Flight Educators (SAFE). Aviation is a passion for Mr. Wilt.

An Introduction to Electricity

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The progress made in aviation is closely related to the advancements made in electricity and its offshoot technology, electronics. For the first few decades of flight, an A & E (Airplane and Engine) mechanic needed to know little more about electricity than the way to coax a healthy spark from a magneto. Then, up through World War II, aircraft electrical systems consisted of no more than DC generators and batteries to operate the starters, lights, radios, and in some installations, retractable landing gear and flaps. Only a few of the largest aircraft had AC electricity, and this was only for special purposes and was usually produced by DC-powered rotary inverters.

rotary inverter. A self-contained motor-generator in which a DC motor drives an AC generator.

Electronic communications and navigation have made flight so efficient that even small general aviation aircraft are equipped with electronic equipment that is far more sophisticated than that installed in transport aircraft immediately after World War II.

The proliferation of computerized monitoring systems and automatic controls in modern aircraft has made in-depth knowledge of electricity essential for the aviation maintenance technician of the twenty-first century.

This text, *Practical Electricity for Aviation Maintenance Technicians*, is written to furnish background knowledge to allow you to better understand technical manuals and more advanced texts on specialized electrical and avionics equipment.

avionics. The branch of technology that deals with the design, production, installation, use, and servicing of electronic equipment installed in an aircraft.

The History of Electricity

For years we did not know exactly what electricity was, but we were able to use it to do useful work. Within the past five decades, however, we have learned much more about electricity, and the more we learn about it, the more practical uses we find for it.

Centuries ago, it was discovered that when a piece of hardened tree rosin, called amber, was rubbed with sheep's wool, the amber attracted tiny pieces of straw. But when the straw touched the amber, an invisible force pushed the straw away.

Because of these strange happenings, the theory was formulated that there was some kind of invisible fluid on the wool and the amber. The fluid was called "electrik," after the Greek word for amber. There were thought to be two conditions: a lack of fluid and an excess of fluid. When an object having an excess of this invisible fluid was touched by an object having a lack of it, the electrik left one object and traveled to the other, often causing a spark as it went. When both objects had an excess of fluid, or when both had a lack of fluid, they would repel, or push away, from each other.

Lightning, the huge spark that jumps between clouds or from a cloud to the ground, seemed to prove this theory. And certain terms were developed to explain what was happening.

An object having an excess of electrik was said to be "positive," and, in written explanations, a plus (+) sign was used to show this condition. The object having a lack of electrik was called "negative," and this was shown by a minus (–) sign. When electrik passed from one object to another, it was said that "current" flowed between them.

This theory and its explanation worked quite well for years, even though no one knew exactly what it was that flowed or what caused the flow. Today, we know that this flow is made up of invisible particles of matter called electrons.

Knowing what it is that flows in an electrical device and understanding the way we can control this flow enables us to use this invisible force to accomplish almost unbelievable feats.

Atomic Makeup

The study of physics teaches that all matter is made up of slightly more than one hundred different chemical elements whose smallest particles are called atoms.

The nucleus, or center, of an atom is made up of positive electrical charges called protons, and neutrons, which have the same amount of mass as a proton, but with no electrical charge. Spinning around the nucleus in rings—or shells—are negatively charged particles called electrons. The mass of an electron is only about 1/1,846 that of a proton, but its negative electrical charge is exactly as strong as the positive charge of a proton.

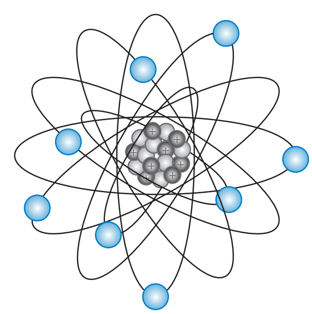


Figure 1-1. *Electrons circle the nucleus of an atom in shells, with all the electrons in each shell circling the nucleus the same distance from the center.*

Most atoms are electrically balanced. This means that there are exactly the same number of electrons circling around the nucleus as there are protons in the nucleus.

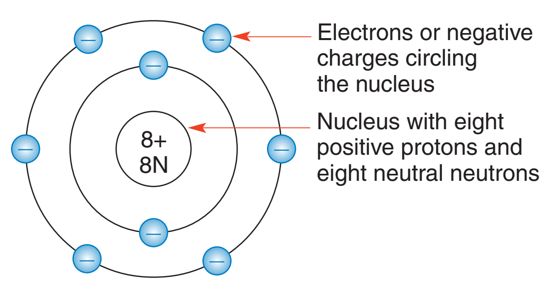


Figure 1-2. *This is an atom of oxygen which has two electrons in its inner shell and six in its outer shell. There are eight protons and eight neutrons in the nucleus.*

chemical element. One of the fundamental building blocks of which all matter is made. There are just a few more than 100 different chemical elements. Some elements exist in nature by themselves, and others exist only in chemical compounds. Oxygen, carbon, gold, silver and hydrogen are examples of chemical elements.

atom. The smallest particle of a chemical element that can exist, either alone or in combination with other atoms.

chemical compound. A combination of two or more atoms of chemical elements that have joined together to form molecules.

molecule. The smallest particle of a substance that retains all the properties of the substance. A molecule is made up of one or more atoms.

proton. The positively charged particle in the nucleus of an atom.

neutron. The particle in the nucleus of an atom that has the same mass as a proton but no electrical charge.

All electrons and all protons are exactly alike. It is the number of protons and electrons in an atom that makes an atom of one element different from an atom of another element. Figure 1-3 shows diagrams of atoms of hydrogen, neon, sulfur, and copper, all very different from each other. Hydrogen is a very active, lighter-than-air gas, neon is an inert gas, sulfur is a nonmetal that resists the flow of electricity, and copper is a metal and an excellent conductor of electricity.

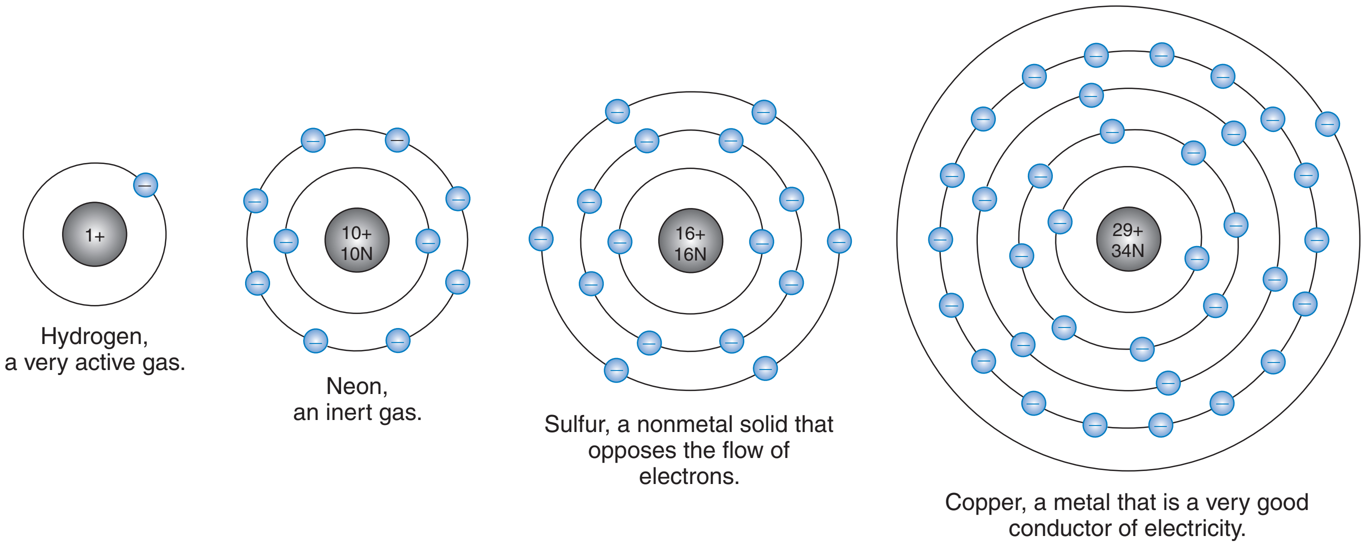


Figure 1-3. *The electrons, protons, and neutrons in all atoms are exactly alike. Materials differ from each other because of the number and arrangement of the electrons, protons, and neutrons in their atoms.*

Figure 1-3 shows that the electrons circle the nucleus in shells, and some atoms have as many as seven shells. Each shell can hold only a certain number of electrons. For example, the first shell can hold only two electrons, the second shell can hold eight, the third can hold eighteen, and so on.

Valence Electrons

Regardless of the number of electrons the inner shells can hold, the outer shell can never hold more than eight electrons. This outer shell is called the valence shell, and its electrons are called valence electrons. It is these valence electrons that are of interest in the study of electricity, as they are the ones that give an atom its electrical characteristics.

valence electron. Electrons that spin around the nucleus of an atom in its outer shell. It is the number of valence electrons that determines the chemical and electrical characteristics of an element.

Chemical elements are classified by their valence electrons into three electrical categories: conductors, insulators, and semiconductors.

Conductors

An electrical conductor has between one and three electrons in its valence shell, and these electrons are easily attracted away from the atom by an outside electrical force. They then move freely through the material. Silver, gold, and copper have only one electron in their outer shell, and they are excellent conductors of electricity.

conductor. A material whose valence electrons are held in the atom with a weak force and are therefore able to be moved from one atom to another by a small amount of electrical pressure.

Insulators

Insulators are made of materials whose atoms have between five and eight electrons in their valence shells, and these materials do not readily give up any of their valence electrons. A strong electrical force is needed to pull electrons from the atoms in insulators. Nitrogen, sulfur, argon, and bromine are good insulators.

insulator. A material whose valence electrons are so tightly bound to the atom that they resist any force that tries to move them from one atom to another.

semiconductor. A material whose electrical conductivity is between that of a conductor and an insulator. Semiconductor materials have four valence electrons and may have their electrical characteristics modified by "doping" them with elements having three electrons (P-material) or five electrons (N-material).

negative ion. A negatively charged atom that has more electrons spinning around its nucleus than there are protons in the nucleus.

positive ion. A positively charged atom that has fewer electrons spinning around its nucleus than there are protons in the nucleus.

electrolyte. A chemical solution that conducts electrical current by releasing ions that unite with oppositely charged ions on the electrodes.

Semiconductors

Semiconductors are a special group of elements that have four electrons in their valence shell. Alloying these elements with others produces materials that have extremely useful electrical characteristics.

The two most widely used semiconductors are silicon and germanium, and because of the importance of semiconductors in electronics, they are covered in more detail in Chapter 5 (beginning on page 111).

Ions

Most atoms are balanced; that is, they have the same number of electrons as protons. But it is possible for an atom to either gain an electron or lose one, and when it does, the atom is no longer balanced—it has become charged, and these charged atoms are called ions. For example, if an atom gains an electron, it has more negative charges than positive, and it becomes a negative ion. If a balanced atom loses an electron, it has lost some of its negative charge and has become a positive ion. The nucleus of the atom does not change, but when an atom becomes an ion, its characteristics change and it behaves differently from a balanced atom. For example: two negative ions will repel—or push away from each other—and two positive ions will do the same. But a positive and a negative ion will attract each other and will join, becoming neutral.

Electrons can be made to flow and do useful work any time materials having different electrical charges are joined by a conductor. There are five things that cause electrons to flow: chemical action, magnetism, heat, light, and pressure. Here, however, we will think only about the way chemical action forces them to flow.

In a common carbon-zinc flashlight battery, a chemical action takes place between the zinc and the ammonium chloride electrolyte that causes some of the zinc atoms to give up electrons that accumulate on the can, leaving positive zinc ions. These positive ions give the electrolyte paste a positive charge, which attracts electrons away from the carbon rod to restore the electrical balance in the paste. This action leaves the zinc can with an excess of electrons (a negative charge) and the carbon rod with too few electrons (a positive charge). Modern battery designs seldom use the carbon-zinc technology, but use technologies that provide longer lasting or rechargeable capabilities. To mention a few well-known types, alkaline batteries use a zinc-manganese dioxide chemical reaction that allows for a longer lasting and sometimes rechargeable capability. Nickel-cadmium and lithium-ion batteries are popular because they allow the consumer to recharge the battery many times before it must be replaced.

If a conductor, such as a copper wire, and a light bulb are connected between the zinc can and the carbon rod, the extra electrons in the zinc will flow to the carbon rod. This flow of electrons causes the bulb to give off light and heat. This is the work done by these electrons.

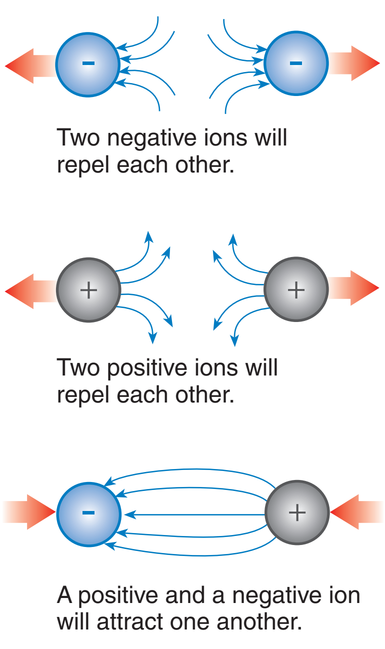


Figure 1-4. *Ions with like charges repel each other, while ions with unlike charges attract each other.*

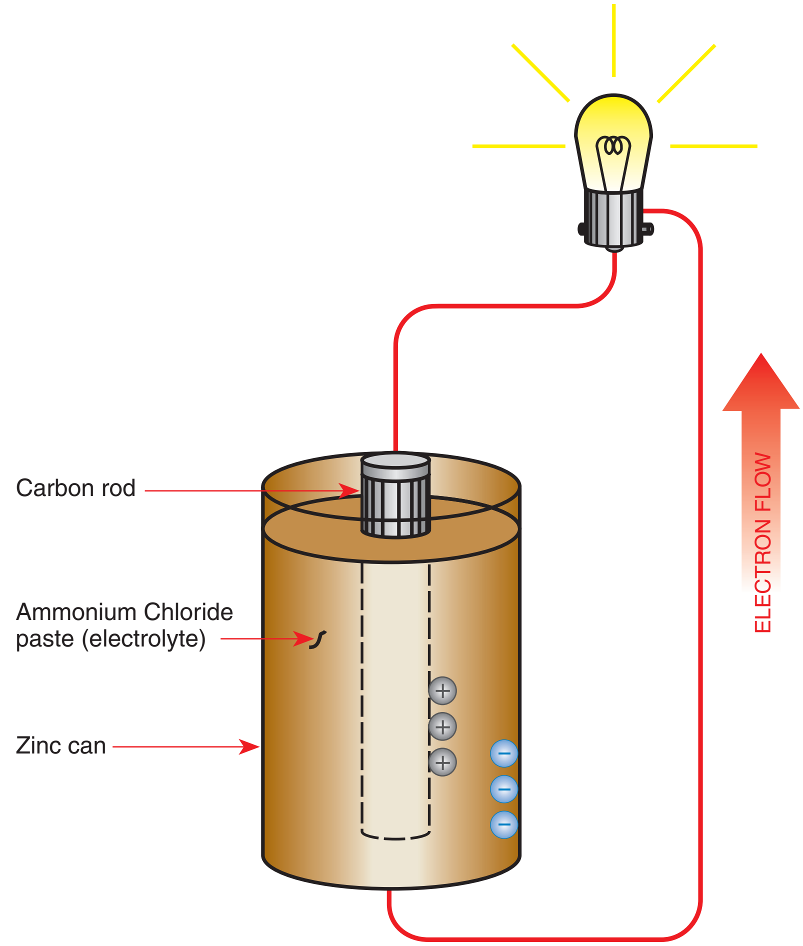


Figure 1-5. *Chemical action in a battery changes neutral zinc atoms into positive zinc ions. This leaves extra electrons on the can and gives the can a negative charge. Positive ions in the electrolyte pull electrons away from the carbon rod and leave it with a positive charge.*

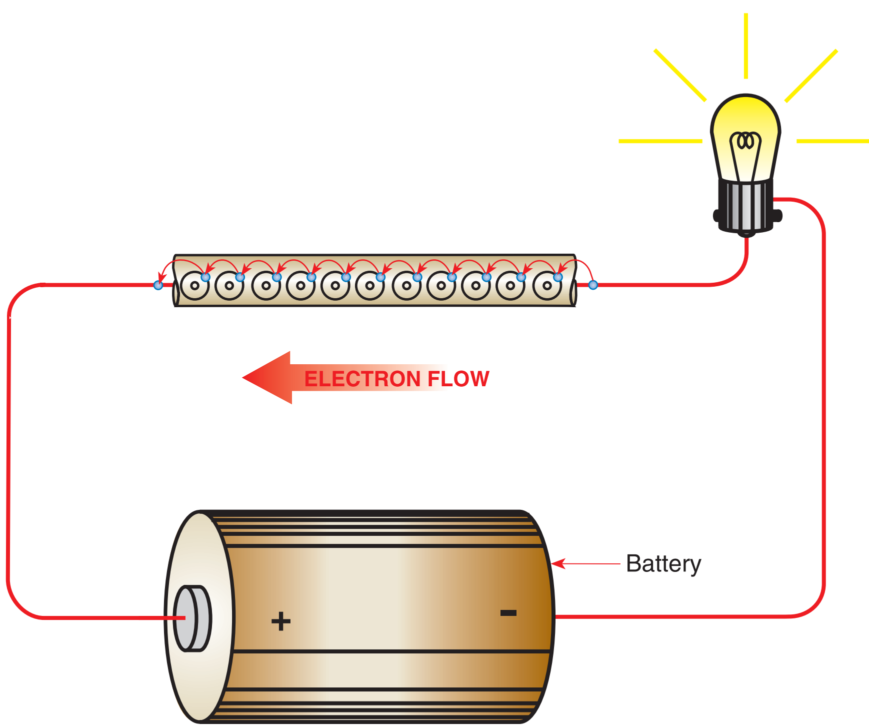


Figure 1-6. *When a copper wire is connected across a battery, electrons leave its negative end, flow through the load, and return to the positive end. This movement of electrons is called electron flow, or negative current.*

When one electron leaves the battery, it knocks a valence electron out of a copper atom and replaces it. The electron that has been knocked out now knocks an electron out of another atom and replaces it. This action continues through the wire until one electron is knocked out of the copper and goes into the positive terminal of the battery.

Current flow does not consist of one electron leaving the zinc can and rushing through the wire directly to the carbon rod; instead, every time one electron enters the end of the wire at the zinc can, another electron leaves the end of the wire at the carbon rod. Electron movement between the time an electron enters one end of the wire until another electron leaves the other end takes place at the speed of light, about 300,000,000 meters per second, or 186,000 miles per second.

Copper is a very good conductor of electricity, because each atom of copper has only one electron in its valence shell. In a piece of copper wire, there are many billions of atoms, and each atom has one valence electron. When electrons leave the zinc and enter the copper wire, each of them knocks a valence electron out of a copper atom and takes its place. The electrons that are knocked out are called free electrons, and they knock electrons from the valence shell of other copper atoms. Exactly the same number of electrons leave the wire at the positive end of the battery as entered it at the negative end. As long as the wire joins the two ends of the battery, electrons flow, and it is this flow of electrons that makes the entire field of electricity and electronics possible.

Useful Work

When electrons flow through a conductor, two very important things happen: heat is produced in the conductor, and a magnetic field surrounds the conductor. These two things are so important that we will study them in detail.

Direction of the Flow of Electricity

One problem in the study of electricity concerns the direction in which electricity flows. Benjamin Franklin and others who experimented with electricity in the early days thought of it as a fluid which flowed from a high level, which they called positive (or plus) to a lower level, called negative (or minus). This flow was called current, and the assumption made about its direction of flow was logical. Many textbooks on electricity were written that defined current as the flow of electricity that travels from the positive terminal of a source of electrical energy to its negative terminal.

As more was learned about atoms, with their protons and electrons, it was discovered that it is actually the electrons that move in an electrical circuit, or path. And because electrons are negative charges of electricity, they actually migrate toward the positive terminal, not away from it, just opposite of what was originally considered. This movement is called electron flow, or electron current.

As electrical technology has developed into the solid-state age, the assumption of this direction of flow has caused confusion. This is because many of the symbols used in solid-state circuits have arrows pointing in the direction *opposite* that of electron flow. The proliferation of solid-state electronics has brought about a standardized way of thinking about the flow of electricity. In the study of electron physics, the movement of electrons and holes is considered. However, in the study of practical circuits outside of the components, the flow is thought of as negative current (from negative to positive) or positive current (from positive to negative). Almost all modern circuit analysis uses the concept of positive current.

circuit. The complete path followed by electrons as they leave one terminal of a power source and return to the other.

hole. A concept used to explain a condition in a semiconductor material. A hole is a location in an atomic covalent bond where there should be an electron, but there is none. Holes act as positive charges.

negative current. The flow of electrons in a circuit from the negative terminal of the source of electrical pressure to the positive terminal. Negative current is also called electron current and its direction of flow is opposite the arrows in semiconductor symbols.

positive current. An assumed flow of current from the positive terminal of the source of electrical pressure to the negative terminal. Positive current follows the arrows in semiconductor symbols and is sometimes spoken of as conventional current.

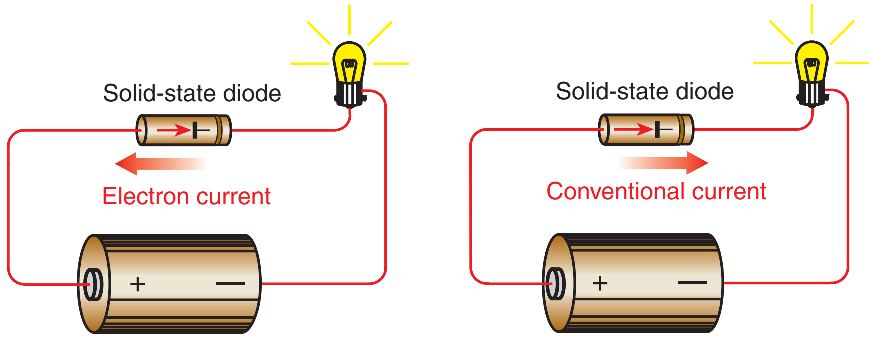


Figure 1-7. *Negative current flows from the negative terminal of the battery through the diode and the load (the light bulb), back to the positive terminal of the battery. This flow is opposite the arrowhead in the symbol for the solid-state diode. The concept of negative current is seldom used in the practical study of Directional Current (DC) electrical circuits.*

Positive current is considered to flow from the positive terminal of the battery, through the load and the diode, to the negative terminal. Positive current flows in the direction of the arrowhead in the solid-state diode symbol and is the concept used in most modern DC circuit analysis.

It makes no difference which direction you choose when considering flow in an electrical circuit, but it must be thought of as going in the same direction all the time.

In this text, unless specifically stated otherwise, when the term “current” is used, it is positive current (flowing from positive to negative) which follows the arrows in component symbols. This direction of flow is sometimes called conventional current.

Types of Electricity

There are two basic types of electricity: static and current. In static electricity, electrons accumulate on a surface and remain here until they build up a pressure high enough to force their way to another surface or device which has fewer electrons. Static electricity is generally a bother, and steps must be taken to prevent its formation and/or to get rid of it.

Current electricity, on the other hand, is the type most often used. There are two types of current electricity, Direct Current (DC), in which the electrons always flow in the same direction, and Alternating Current (AC), in which the electrons periodically reverse their direction of flow.

Static Electricity

When you slide across the plastic seat covers of an automobile, the friction between your clothing and the seat covers causes your clothes to pick up an excess of electrons from the seat. This is exactly the same thing described earlier when a piece of amber was rubbed with sheep’s wool.

If there is no conductor between your body and the car to make a path for these electrons to leak off, your body holds the extra electrons and is said to be charged because there is an electrically unbalanced condition between it and the car. But as soon as you touch or even come close to a bare metal part of the car, the extra electrons leave and jump to the metal in the form of a spark. This accumulation and holding of electrical charges is called static electricity.

Lightning is just a big spark. Friction of the air moving up and down inside the clouds causes water droplets in the clouds to become charged, and when enough electrons have concentrated in a cloud, the electrical pressure they produce forces them to move through the air. These electrons jump between clouds having different charges or from a cloud to the ground. This is the gigantic spark we call lightning.

static electricity. Electrical pressure produced by an excess of electrons (a negative charge) or a deficiency of electrons (a positive charge). Static charges accumulate on an insulated surface and remain in a still, or static, condition until a conductive path is provided to either an oppositely charged surface or to ground.

current electricity. Electricity in which electrons flow in a circuit to create a magnetic field and produce heat.

Direct Current (DC). Current electricity in which the electrons flow in the same direction all of the time.

Alternating Current (AC). Current electricity in which the direction of electron flow continually changes its amplitude and periodically reverses its direction.

As mentioned earlier, an object with an excess of electrons is negatively charged, and an object which has lost its electrons and wants to get them back is positively charged. Two positively charged or two negatively charged objects repel each other, while objects having opposite charges attract. When oppositely charged objects touch, the extra electrons travel from the negative object to the one with the positive charge and they become discharged, or electrically neutral.

While static electricity has some uses, it is most often thought of as a nuisance. So a path must be provided to allow the electrons to pass harmlessly from one charged object to another before the charges can build up enough pressure to cause a spark to jump.

grounding. Electrically connecting an aircraft or component to the earth ground so all static electrical charges can be safely dissipated.

bonding. Electrically connecting components of an aircraft so the entire aircraft has the same electrical potential.

In addition to producing a mild shock when you touch the metal part of your car, static electricity can cause radio interference and can damage sensitive electronic components. It is possible, on a dry day, that just taking a few steps on a nylon carpet can build up more than 10,000 volts of static electricity on your body. When you have accumulated this much charge and touch some electronic components, they can be destroyed. When working with sensitive electronic equipment, always wear a grounded wrist strap to bleed off any charge on your body before handling the equipment.

Many airplanes have static discharge points or wicks installed on the trailing edges of the control surfaces. These devices allow the static charges that build up on the control surfaces as air flows over them to discharge harmlessly into the air and not cause static interference in the radio equipment.

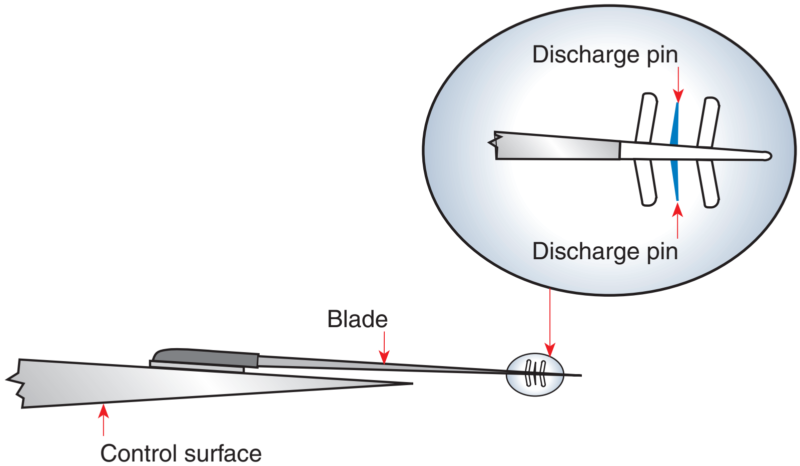


Figure 1-8. *Static discharge points are installed on the trailing edge of control surfaces to bleed off the static charges that build up as air flows over the surfaces.*

Static electricity causes a serious fire hazard when aircraft are being fueled or defueled. The flow of gasoline or turbine fuel in the hose produces enough static electricity to cause a spark to jump and ignite explosive fumes.

Current Electricity

Current electricity is the form of electricity that has the most practical applications. A source of electrical energy such as a battery or alternator acts as a pump that forces electrons to flow through conductors. In this study of practical electricity, this flow is called current and because we are considering it to flow from positive to negative, it is positive current.

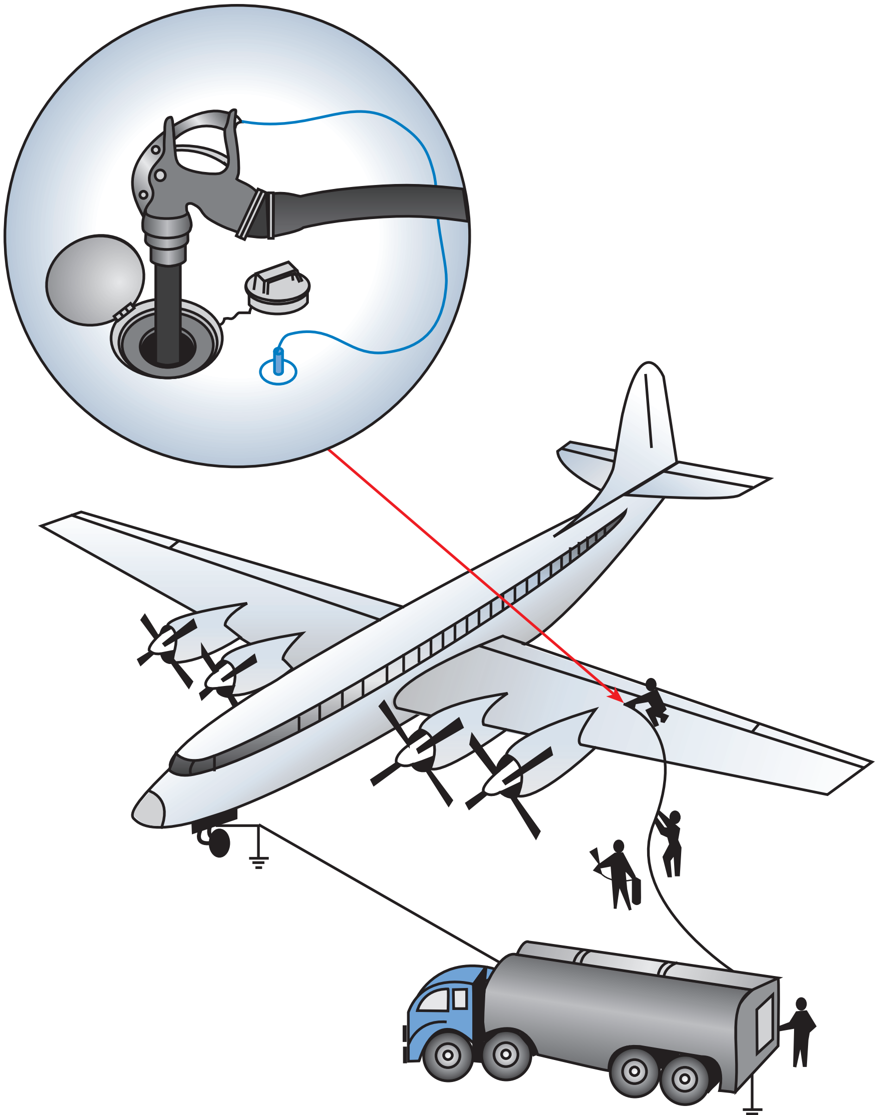


Figure 1-9. *Aircraft must be electrically grounded before they are fueled. Bonding wires connect the aircraft and the fueling truck or pit together, and both of them are connected to the earth ground so that static charges that build up during fueling can pass harmlessly to ground.*

For current to flow, there must be a complete path from one terminal of the source back to the other terminal. Figure 1-10 shows a complete electrical circuit. The battery is the component in which chemical energy is changed into electrical energy, and current is forced out of the positive terminal, through the switch, the control device, to the lamp. The lamp acts as the load, which changes electrical energy into heat and light. The current then returns to the negative terminal of the battery. Current flows as long as the switch is closed, forming a complete path.

The electrical pressure that forces current through the circuit is measured in volts, with the basic unit of electrical pressure being one volt. Electrical current is measured in amperes or, as we more commonly call it, in amps. One amp is the flow of one coulomb per second, and one coulomb is 6.28 billion billion (6.28×10^{18}) electrons. All conductors have some resistance which opposes the flow of electrons in much the same way that friction opposes mechanical movement. The basic unit of electrical resistance is the ohm. One volt of electrical pressure will force 1 amp of current to flow through 1 ohm of resistance.

voltage. Electrical pressure that causes current to flow in a circuit.

current. The flow of electrons in a circuit.

resistance. Opposition to the flow of current in a circuit.

power. The ability of an electrical device to do work.

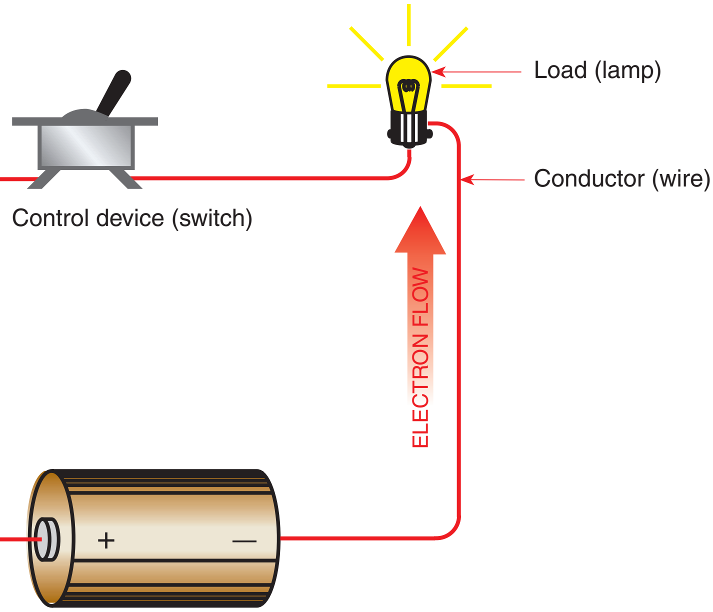


Figure 1-10. *This is a complete electrical circuit. When the switch is closed, current flows from the positive terminal of the battery through the lamp, where there is enough opposition that the filament gets white hot. After all of the pressure from the battery is dissipated by the lamp, the current returns to the negative terminal of the battery.*

When current flows through a resistor, power is dissipated and voltage is dropped. The voltage across a resistor can be measured with a voltmeter in the same way as the voltage produced by a battery. This voltage is caused by current (I) flowing through the resistor (R), and it is called an IR drop, or a voltage drop. The end of the resistor where the positive current enters is the positive end, and the end where it leaves is the negative end.

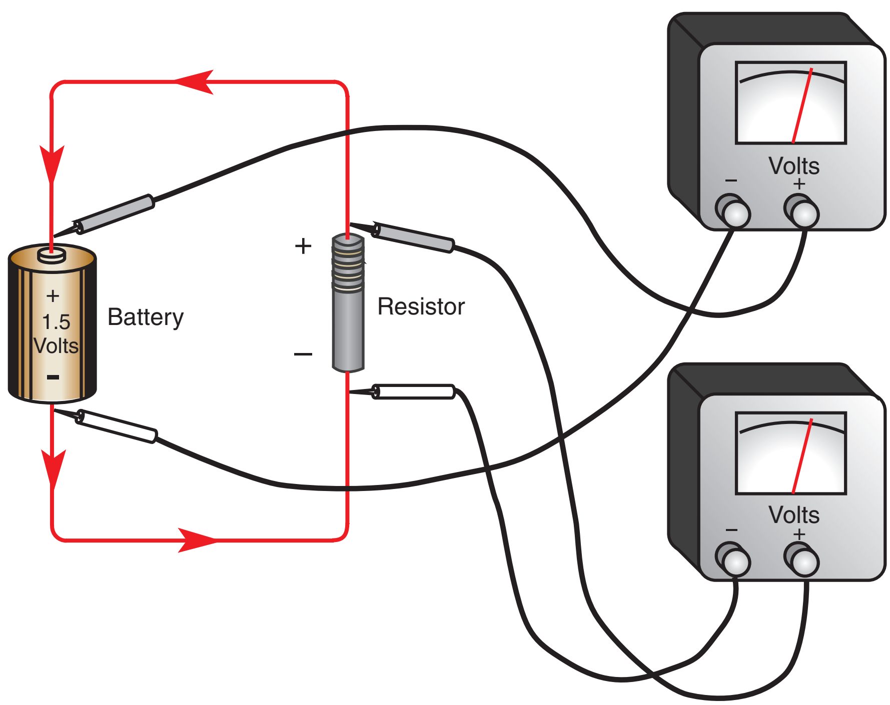


Figure 1-11. *A battery is a source of electrical pressure that is also called an EMF, electromotive force, potential, or potential difference. All are measured in volts, and all mean essentially the same thing.*

When current flows through a resistance, power is used, or dissipated, and voltage is dropped. The voltage dropped across a resistor can be measured with a voltmeter in the same way as the voltage produced across the terminals of a battery.

Electrical pressure caused by changing some other form of energy into electrical energy may be called an electromotive force, an EMF, a potential difference, or just a potential. Electrical pressure caused by current flowing through a resistance is not a source of electrical energy; it is a drop in the electrical pressure. This voltage is usually called a voltage drop or an IR drop because the amount of drop may be found by multiplying the current (I) by the resistance (R) through which it flows. These terms for voltage are often used interchangeably, and all of them use the volt as the basic unit of measurement.

Production of Electricity

Electricity is a form of energy, and we can neither create nor destroy energy. But we can change other forms of energy into electricity, and we can also change electricity into other forms.

Electricity from Heat (Thermoelectricity)

Thermoelectricity is electricity produced by heat. A good example of this is the thermocouple system used to get an indication of the exhaust gas temperature in an aircraft turbine engine or the cylinder head temperature (CHT) of a reciprocating engine.

The thermocouple used with a cylinder head temperature indicator shown in Figure 1-12 is made up of a loop of two different kinds of wire embedded in a spark plug gasket at one end to form a hot, or measuring, junction. The coil of a current-measuring CHT indicator is connected between the wires at the other end to form a cold, or reference, junction. A voltage is produced in the thermocouple whose magnitude is determined by the difference in temperature between the hot and cold junctions. This voltage difference causes a current to flow that is proportional to the temperature of the cylinder head.

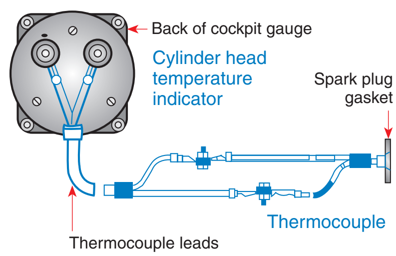


Figure 1-12. *A thermocouple, made of two different kinds of wire, produces electricity when one of its junctions is heated. The amount of current that flows is determined by the difference in the temperature between the hot and cold junctions and by the resistance of the wires.*

thermoelectricity. The flow of electrons caused by heat in a metal or in a junction of two metals.

thermocouple. A device used to change heat energy into electrical energy. A thermocouple is made up of two dissimilar metal wires with their ends joined to form two junctions. The amount of current that flows in the wires is determined by the difference in temperature between the junctions and by the resistance of the wires.

Electricity from Chemical Action

Chemical energy can be changed into electricity. A simple flashlight battery is made of a zinc can filled with a moist electrolyte paste, and a carbon rod is supported in the center of the paste so that it does not touch the can.

A chemical action between the electrolyte and the zinc changes the zinc into zinc chloride, and when this change takes place, electrons are released from the zinc. If a wire and a light bulb connect the zinc to the carbon rod, electrons will flow from the zinc to the carbon. The zinc can is the negative terminal of this battery, and the carbon rod is the positive terminal.

Aircraft batteries are more complex, of course, than the simple flashlight battery. All aircraft batteries are composed of secondary cells that can be recharged by forcing electrons from the alternator or generator through them. Lead-acid and nickel-cadmium batteries are commonly used, and both types are discussed in Chapter 6 beginning on page 129.

primary cell. A nonreversible electrochemical cell that converts chemical energy into electrical energy. Once the chemical energy is depleted, it cannot be restored.

secondary cell. A reversible electrochemical cell that converts chemical energy into electrical energy. Once the chemical energy is depleted, it can be restored by forcing electrons to flow through it in the direction opposite to the discharge flow.

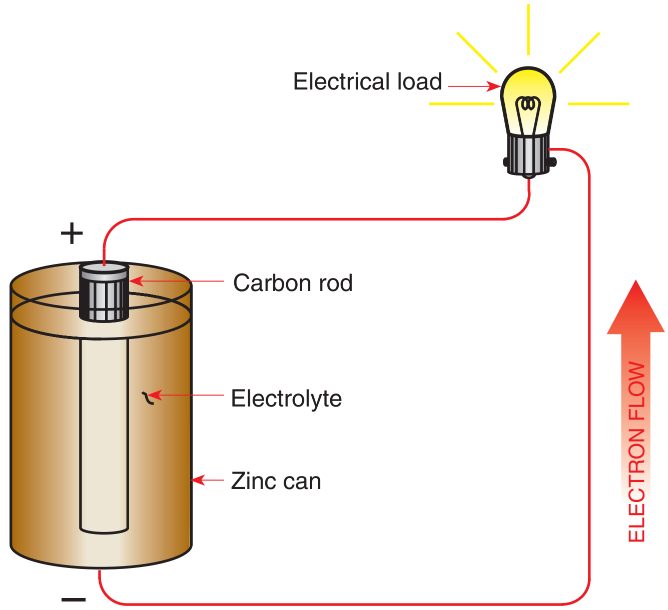


Figure 1-13. *A flashlight battery is a primary cell that changes chemical energy into electricity. Chemical action changes the zinc of the can into zinc chloride, and when this change is made, electrons are released. The carbon rod is positive and the can is negative. When a wire connects the zinc can to the carbon rod, positive current flows from the carbon rod to the can through the electrical load, the lamp.*

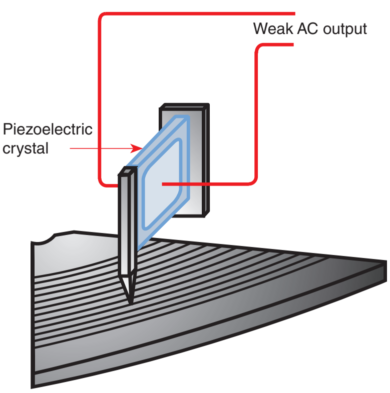


Figure 1-14. *A piece of piezoelectric crystal produces electricity when it is bent or twisted by the needle riding in the grooves of a phonograph record.*

piezoelectricity. Electricity produced when certain crystalline material such as quartz is deformed (twisted or bent) by pressure.

quartz (silicon dioxide). A colorless, transparent, crystalline rock-forming mineral that has piezoelectric characteristics. Quartz is the most abundant mineral found in nature and is the basis of many semiconductor devices.

Electricity from Pressure (Piezoelectricity)

When certain types of crystals are bent or distorted, an electrical pressure difference exists across the opposite faces of the crystal. This action is reversible. If pulses of electricity are applied to the opposite faces of a crystal it will distort. This piezoelectric characteristic of crystals is used in crystal microphones and crystal phonograph pickups, as well as producing a stable frequency standard for radio transmitters.

Electricity is produced in a crystal phonograph pickup, as seen in Figure 1-14. A piece of quartz or Rochelle salt (potassium sodium tartrate) is mounted between two metal plates that hold the phonograph needle. These plates and the crystal are twisted by the needle when it rides in the grooves of the phonograph record. When the crystal is bent, it forces electrons from one plate to the other.

Electrons travel through wires from one plate, through an outside circuit, and back to the other plate as long as the crystal is being twisted. This current is very weak, and for practical use, it must be amplified, or made stronger. The outside circuit mentioned contains an amplifier to increase the amount of current. Electricity produced by pressure is called piezoelectricity, and it is alternating current.

Electrons move through the external circuit from one side of the crystal to the other. The amplitude of this weak current must be increased by an amplifier so that it can drive a speaker.

Electricity from Light (Photoelectricity)

Light is another form of energy that can be changed into electricity. When certain chemical elements are exposed to light, they absorb energy from the light and release electrons. Photographic light meters use this type of energy exchange.

Today, the space program has brought us powerful solar cells that absorb light energy from the sun and release electrons, which are used to power electrical devices. Solar cells can be activated by light from any source and are often used to power such devices as our orbiting satellites.

Electricity produced by light is called photoelectricity, and it is direct current.

photoelectricity. Electricity produced by light. When light strikes certain types of semiconductor material, light energy is absorbed and electrons are released. When current flows through some semiconductor devices, photons of light energy are released.

solar cell. A silicon semiconductor device that converts light energy directly into electrical energy.

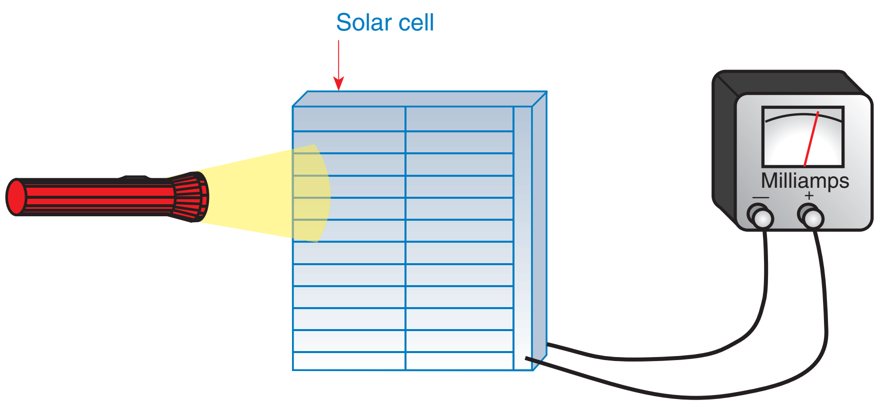


Figure 1-15. *When light strikes a solar cell, electrons are driven from it to produce a flow of current.*

Electricity from Magnetism

By far the most important exchange of energy is between magnetism and electricity. Invisible lines of magnetic force, called magnetic flux, pass between the poles of a magnet, and any time a conductor cuts across this flux, electrons are forced to move through the conductor.

Generators and alternators, driven by aircraft engines, rotate conductors through magnetic fields to produce electricity. All of these generators produce alternating current, but in some generators it is changed into direct current by solid-state diodes or a commutator before it leaves.

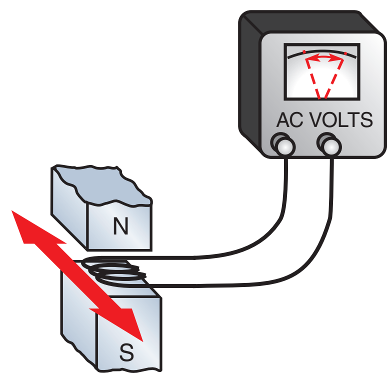


Figure 1-16. *When a coil of wire is moved back and forth so that it cuts across a magnetic field, electrons are forced to flow in the wire. This is the way almost all of the electricity used in aircraft electrical systems is produced.*

Electrical Relationships

Voltage, current, resistance, and power are the basic characteristics of electricity, and one important law propounded by the German physicist Georg Simon Ohm, who lived between 1787 and 1854, shows how these characteristics are related. This law, known as Ohm's law, ties all of these characteristics together in such a way that when we know any two of them, we can find any of the others.

Ohm's law essentially states that the current in a circuit is directly proportional to the circuit voltage and inversely proportional to the resistance of the circuit. Power is the product of voltage and current.

Ohm's Law

Electrical pressure is measured in volts, current in amps, and resistance is measured in ohms. And there is a relationship between these values: one volt of electrical pressure will force one amp of current through one ohm of resistance.

Our main use of electricity is to perform useful work, and in order to perform work, power is needed. The unit of electrical power is the watt, and one watt is the amount of power produced when one amp of current is pushed along by a pressure of one volt.

magnetism. The property possessed by certain materials that causes them to attract or repel other materials having this same property. Magnetism also causes electrons to flow in a conductor when it is moved through the lines of magnetic flux that extend between the poles of a magnet.

rectifier. A device that changes AC into DC.

solid-state diode. A semiconductor device that allows electrons to flow through it in one direction but blocks their flow in the opposite direction.

commutator. A mechanical rectifier mounted on the armature shaft of a DC generator or motor to change AC into DC.

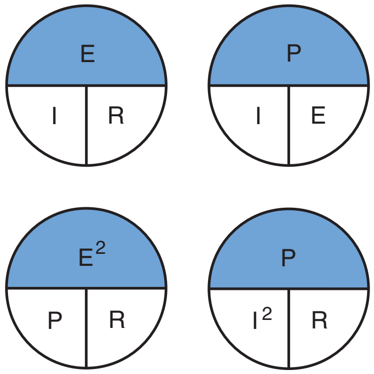


Figure 1-17. *Relationship between voltage, current, resistance, and power in an electrical circuit. The top quantity is equal to the product of the two bottom quantities, and one bottom quantity is equal to the top quantity divided by the other bottom quantity.*

Mechanical power is the rate of doing work, and its basic unit in the U.S. customary system is the horsepower, the amount of power needed to lift 33,000 pounds of weight one foot in one minute, or 550 pounds of weight one foot in one second. Electrical power can be changed directly into mechanical power, since 746 watts of electrical power is equal to one horsepower.

To use these electrical values in formulas, it is customary to assign letters to each of them. Voltage is represented by the letter E, which stands for electromotive force. The symbol for current is the letter I, which comes from the intensity of the current. R is used for resistance, and P is used for power. A more common use of the symbol for voltage is (V), though E and V can be used interchangeably as they mean the same thing electrically.

Ohm's law states that the current flowing in a circuit is directly proportional to the applied voltage—the more voltage, the more current. And it is inversely proportional to the resistance through which the current flows—the more resistance, the less current. This may be stated by the formula:

$$I = \frac{E}{R}$$

The Ohm's law relationships are easy to visualize with the circles in Figure 1-17. The value in the top half of each circle is equal to the two bottom values multiplied together, and either of the two bottom values may be found by dividing the top value by the other value on the bottom.

The four circles in Figure 1-17 produce twelve formulas, and if we know any two values and use these formulas, we can find any other value.

$E = I \cdot R$	$P = I \cdot E$	$E = \sqrt{P \cdot R}$	$P = I^2 \cdot R$
$I = E \div R$	$I = P \div E$	$P = E^2 \div R$	$I = \sqrt{P \div R}$
$R = E \div I$	$E = P \div I$	$R = E^2 \div P$	$R = P \div I^2$

Examples of Ohm's law problems:

1. Find the voltage needed to force 10 amps through a resistance of 20 ohms.

$$\begin{aligned} E &= I \cdot R \\ &= 10 \cdot 20 \\ &= 200 \text{ volts} \end{aligned}$$

2. Find the amount of current that 24 volts can force through a resistance of 144 ohms.

$$\begin{aligned} I &= E \div R \\ &= 24 \div 144 \\ &= 0.167 \text{ amp} \end{aligned}$$

3. Find the amount of resistance needed to drop 6 volts when 3 amps of current is flowing.

$$\begin{aligned} R &= E \div I \\ &= 6 \div 3 \\ &= 2 \text{ ohms} \end{aligned}$$

4. Find the amount of power used when 4 amps is being forced through 16 ohms of resistance.

$$P = I^2 \cdot R$$
$$= 4^2 \cdot 16$$
$$= 256 \text{ watts}$$

5. Find the voltage needed to produce 100 watts of power when 6 amps is flowing.

$$E = P \div I$$
$$= 100 \div 6$$
$$= 16.7 \text{ volts}$$

6. Find the amount of current that must flow under a pressure of 6 volts to produce 48 watts of power.

$$I = P \div E$$
$$= 48 \div 6$$
$$= 8 \text{ amps}$$

7. Find the amount of resistance in a circuit in which 100 volts is producing 200 watts of power.

$$R = E^2 \div P$$
$$= 100^2 \div 200$$
$$= 50 \text{ ohms}$$

8. Find the amount of power developed when 24 volts forces 6 amps to flow in a circuit.

$$P = I \cdot E$$
$$= 6 \cdot 24$$
$$= 144 \text{ watts}$$

9. Find the voltage needed to produce 100 watts of power when the resistance is 25 ohms.

$$E = \sqrt{P \cdot R}$$
$$= \sqrt{100 \cdot 25}$$
$$= \sqrt{2500}$$
$$= 50 \text{ volts}$$

10. Find the amount of current needed to produce 60 watts of power in a circuit having a resistance of 20 ohms.

$$I = \sqrt{P \div R}$$
$$= \sqrt{60 \div 20}$$
$$= \sqrt{3}$$
$$= 1.73 \text{ amps}$$

11. Find the amount of resistance needed for 16 amps of current to produce 800 watts of power.

$$R = P \div I^2$$
$$= 800 \div 16^2$$
$$= 800 \div 256$$
$$= 3.12 \text{ ohms}$$

12. Find the amount of power produced when 120 volts are applied to a resistance of 6 ohms.

$$
\begin{aligned}
P &= E^2 \div R \\
&= 120^2 \div 6 \\
&= 14{,}400 \div 6 \\
&= 2{,}400 \text{ watts}
\end{aligned}
$$

13. Find the electrical power equivalent of 6 horsepower.

$$
\begin{aligned}
P &= HP \cdot 746 \\
&= 6 \cdot 746 \\
&= 4{,}476 \text{ watts}
\end{aligned}
$$

14. Find the electrical power required to produce 6 horsepower if the motor is 75% efficient.

$$
\begin{aligned}
P &= (HP \cdot 746) \div \%\ \text{efficiency} \\
&= (6 \cdot 746) \div 0.75 \\
&= 4{,}476 \div 0.75 \\
&= 5{,}968 \text{ watts}
\end{aligned}
$$

Metric Prefixes

All of the work up to this point has been done with the basic units of electricity. But we will not always be dealing with these easy-to-handle numbers. We must often work with very small or very large numbers.

Fortunately, in practical electricity there are methods of handling both of these extremes. When working with both very large and very small numbers, use metric prefixes. In all metric values, these prefixes work in multiples of ten. Figure 1-18 shows the prefixes and powers of ten that help work with very large and very small numbers.

See the way these prefixes work by beginning with numbers greater than one. When considering a distance of 120,000 meters, it is convenient to call it 120 kilometers. The prefix kilo means thousand. In the same way, 250,000,000 hertz is called 250 megahertz, because mega means million. This works the same way with numbers smaller than one. One millimeter is 0.001 meter, 1 microfarad is 0.000 001 farad, 1 nanosecond is 0.000 000 001 second, and one picofarad is 0.000 000 000 001 farad.

1,000,000,000,000	10^{12}	TERA
1,000,000,000	10^{9}	GIGA
1,000,000	10^{6}	MEGA
1,000	10^{3}	KILO
100	10^{2}	HECTO
10	10^{1}	DEKA
1	$\mathbf{10^{0}}$	**UNIT**
0.1	10^{-1}	DECI
0.01	10^{-2}	CENTI
0.001	10^{-3}	MILLI
0.000 001	10^{-6}	MICRO
0.000 000 001	10^{-9}	NANO
0.000 000 000 001	10^{-12}	PICO

Figure 1-18. *Scientific notation and metric prefixes.*

Chapter 1 Review Questions

1. A 12-volt electric motor has 1,000 watts input and 1 horsepower output. Maintaining the same efficiency, how much input power will a 24-volt, 1-horsepower electric motor require? (Note: 1 horsepower = 746 watts)
   a. 1000 Watts.
   b. 2000 Watts.
   c. 500 Watts.

2. What is the operating resistance of a 30-watt light bulb designed for a 28-volt system?
   a. 1.07 ohms.
   b. 26 ohms.
   c. 0.93 ohm.

3. Which term means .001 ampere?
   a. Microampere.
   b. Kiloampere.
   c. Milliampere.

4. A 14-ohm resistor is to be installed in a series circuit carrying .05 ampere. How much power will the resistor be required to dissipate?
   a. At least .70 milliwatts.
   b. At least 35 milliwatts.
   c. Less than .035 watts.

5. The voltage drop in a circuit of known resistance is dependent on
   a. the voltage of the circuit.
   b. only the resistance of the conductor and does not change with a change in either voltage or amperage.
   c. the amperage of the circuit.

6. Convert farads to microfarads by
   a. multiplying farads by 10 to the power of 6.
   b. multiplying picofarads by 10 to the power of 6.
   c. multiplying microfarads by 10 to the power of 6.

7. A circuit has an applied voltage of 30 volts and a load consisting of a 10-ohm resistor in series with a 20-ohm resistor. What is the voltage drop across the 10-ohm resistor?
   a. 10 volts.
   b. 20 volts.
   c. 30 volts.

Continued

8. Which requires the most electrical power? (Note: 1 horsepower = 746 watts)
   a. A 1/5-horsepower, 24-volt motor which is 75 percent efficient.
   b. Four 30-watt lamps arranged in a 12-volt parallel circuit.
   c. A 24-volt anticollision light circuit consisting of two light assemblies which require 3 amperes each during operation.

9. What unit is used to express electrical power?
   a. Volt
   b. Watt
   c. Ampere

10. .002KV equals
    a. 20 volts.
    b. 2.0 volts.
    c. .2 volt.

11. Convert farads to picofarads by:
    a. multiplying farads by 10 to the power of 12.
    b. multiplying microfarads by 10 to the power of -12.
    c. multiplying picofarads by 10 to the power of 12.

12. Materials whose valence electrons are tightly held in their orbits and are able to be dislodged only with a high electrical pressure is called a/an ________________________________ .

13. Electron movement within a conductor is considered to be at the speed of ________________________________ .

14. ____________________________ electricity is the accumulation and holding of an electrical charge.

15. The unit of electrical current is the ________________________________ .

16. Five forms of energy that can be converted into electricity are:
    a. ___________________________________
    b. ___________________________________
    c. ___________________________________
    d. ___________________________________
    e. ___________________________________

17. The potential difference between two conductors insulated from each other is measured in ________________________________ .

18. In a 24-volt circuit, provide the amount of current when the total resistance of the circuit is 200 Ohms. ________________________________

19. Three horsepower equals how many watts of power? ________________________________

20. An avionics system requires 5 amps of current at 24 volts. How much power is required to provide the current required for the system? ____________________

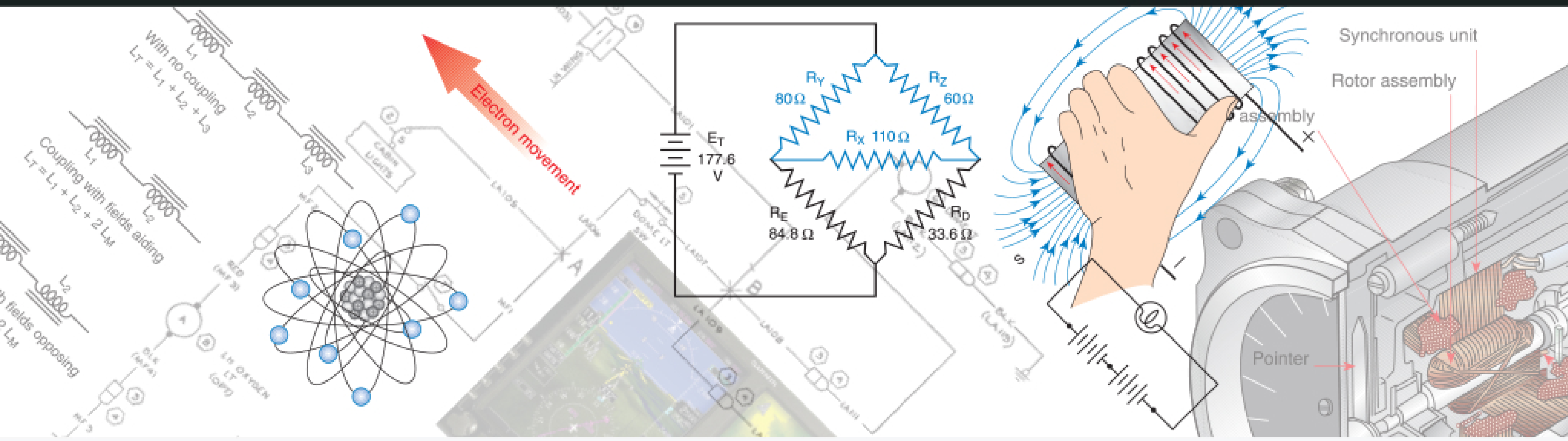
21. Considering Question 20 above, what is the equivalent total resistance of the avionics system? ____________________

22. An aircraft electrical system requires 50 watts of power from the alternator. The voltage output of the alternator is 24 volts. What is the least amount of current output required to power the aircraft electrical system (rounded to the first decimal place)? ____________________

23. Surrounding the nucleus and spinning in a series of rings or shells are negative electrical charges called ____________________ .

24. The unit of electrical resistance is the ____________________ .

25. Electricity produced by generators and alternators is produced using what form of energy? ____________________



Practical Electricity
for Aviation Maintenance Technicians

based on the orginal text by Dale Crane
edited by Dennis W. Wilt

Aircraft electrical systems are not limited to the starter, generator, battery and ignition; the electronics are no longer just the "radio." Today's aircraft are loaded with electric motors, lights, instruments and heaters, and the avionics and electronic controls have made flight profitable, safe, and efficient.

Practical Electricity for Aviation Maintenance Technicians is provided as a classroom text for those preparing to enter the field of aviation maintenance, for those seeking an introduction to electricity, as well as for experienced mechanics who want to increase their knowledge of electricity and electrical systems.

Content covered reflects both legacy aircraft fleets and new technologies, including glass cockpit components (ADC, AHRS, and ADAHRS). The included avionics information is relevant to both U.S. and international operations and details the associated antennas, communications capabilities, emergency locator transmitters (ELT), GPS, and both Air Traffic Control and weather radar. Additionally, surveillance is covered including transponders and ADS-B, as well as satellite and FIS-B weather.

Illustrated extensively throughout, each chapter concludes with review questions for classroom and self-study use; glossary and index included. This book provides a solid foundation for keeping up with this fast moving area of technology.

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