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Electrical Engineering 10 PDH Package

Section 1

Controlling Electrical Hazards

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Controlling Electrical Hazards

U.S. Department of Labor
Elaine L. Chao, Secretary

Occupational Safety and Health Administration
John L. Henshaw, Assistant Secretary

OSHA 3075
2002 (Revised)

This booklet provides a generic overview of a standards-related topic. This publication does not alter or determine compliance responsibilities, which are described in the OSHA standards and the *Occupational Safety and Health Act.* Because interpretations and enforcement policy may change over time, the best sources for additional guidance on OSHA compliance requirements are current administrative interpretations and decisions by the Occupational Safety and Health Review Commission and the courts.

OSHA will make this information available to sensory impaired individuals upon request. Call (202) 693–1999. The teletypewriter (TTY) number is (877) 889–5627.

Contents

Introduction

This booklet provides an overview of basic electrical safety on the job.

Electricity is essential to modern life, both at home and on the job. Some employees — engineers, electricians, electronic technicians, and power line workers, among them — work with electricity directly. Others, such as office workers and sales people, work with it indirectly. Perhaps because it has become such a familiar part of our daily life, many of us don't give much thought to how much our work depends on a reliable source of electricity. More importantly, we tend to overlook the hazards electricity poses and fail to treat it with the respect it deserves.

Why should you be concerned about electrical hazards?

Electricity has long been recognized as a serious workplace hazard, exposing employees to electric shock, electrocution, burns, fires, and explosions. In 1999, for example, 278 workers died from electrocutions at work, accounting for almost 5 percent of all on-the-job fatalities that year, according to the Bureau of Labor Statistics. What makes these statistics more tragic is that most of these fatalities could have been easily avoided.

What OSHA standards address electrical safety?

OSHA standards cover many electrical hazards in many different industries. OSHA's general industry electrical safety standards are published in *Title 29 Code of Federal Regulations (CFR),* Part 1910.302 through 1910.308 — Design Safety Standards for Electrical Systems, and 1910.331 through 1910.335 — Electrical Safety-Related Work Practices Standards.

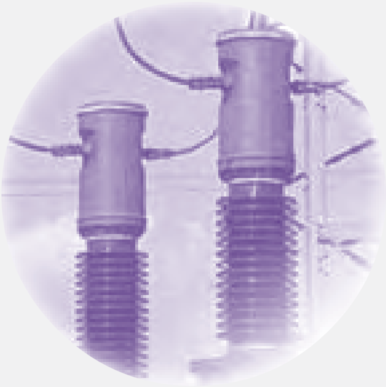
OSHA's electrical standards are based on the National Fire Protection Association Standards NFPA 70, *National Electric Code,* and NFPA 70E, *Electrical Safety Requirements for Employee Workplace*s.

OSHA also has electrical safety standards for the construction industry, in *29 CFR* 1926, Subpart K. OSHA's standards for marine terminals, in *29 CFR* 1917, and for longshoring, in *29 CFR* 1918, reference the general industry electrical standards in Subpart S of Part 1910. The shipyard standards, in *29 CFR* 1915, cover limited electrical safety work practices in *29 CFR* 1915.181.

Although OSHA operates a federal occupational safety and health program, 24 states and 2 territories operate their own OSHA-approved programs. In those states, the standards and other procedures governing electrical safety may not be identical to the federal requirements. They must, however, be at least as effective as the federal standards.

How do OSHA's standards minimize electrical hazards?

OSHA standards focus on the design and use of electrical equipment and systems. The standards cover only the exposed or operating elements of an electrical installation such as lighting, equipment, motors, machines, appliances, switches, controls, and enclosures, requiring that they be constructed and installed to minimize workplace electrical dangers. Also, the standards require that certain approved testing organizations test and certify electrical equipment before use in the workplace to ensure it is safe.



Electricity: The Basics

What affects the flow of electricity?

Electricity flows more easily through some materials than others. Some substances such as metals generally offer very little resistance to the flow of electric current and are called "conductors." A common but perhaps overlooked conductor is the surface or subsurface of the earth. Glass, plastic, porcelain, clay, pottery, dry wood, and similar substances generally slow or stop the flow of electricity. They are called "insulators." Even air, normally an insulator, can become a conductor, as occurs during an arc or lightning stroke.

How does water affect the flow of electricity?

Pure water is a poor conductor. But small amounts of impurities in water like salt, acid, solvents, or other materials can turn water itself and substances that generally act as insulators into conductors or better conductors. Dry wood, for example, generally slows or stops the flow of electricity. But when saturated with water, wood turns into a conductor. The same is true of human skin. Dry skin has a fairly high resistance to electric current. But when skin is moist or wet, it acts as a conductor. This means that anyone working with electricity in a damp or wet environment needs to exercise extra caution to prevent electrical hazards.

What causes shocks?

Electricity travels in closed circuits, normally through a conductor. But sometimes a person's body — an efficient conductor of electricity — mistakenly becomes part of the electric circuit. This can cause an electrical shock. Shocks occur when a person's body completes the current path with:

- both wires of an electric circuit;
- one wire of an energized circuit and the ground;
- a metal part that accidentally becomes energized due, for example, to a break in its insulation; or
- another "conductor" that is carrying a current.

When a person receives a shock, electricity flows between parts of the body or through the body to a ground or the earth.

What effect do shocks have on the body?

An electric shock can result in anything from a slight tingling sensation to immediate cardiac arrest. The severity depends on the following:

- the amount of current flowing through the body,
- the current's path through the body,
- the length of time the body remains in the circuit, and
- the current's frequency.

This table shows the general relationship between the amount of current received and the reaction when current flows from the hand to the foot for just 1 second.

Effects of Electric Current in the Human Body

Current	Reaction
Below 1 milliampere	Generally not perceptible
1 milliampere	Faint tingle
5 milliamperes	Slight shock felt; not painful but disturbing. Average individual can let go. Strong involuntary reactions can lead to other injuries.
6–25 milliamperes (women)	Painful shock, loss of muscular control*
9–30 milliamperes (men)	The freezing current or "let-go" range.* Individual cannot let go, but can be thrown away from the circuit if extensor muscles are stimulated.
50–150 milliamperes	Extreme pain, respiratory arrest, severe muscular contractions. Death is possible.
1,000–4,300 milliamperes	Rhythmic pumping action of the heart ceases. Muscular contraction and nerve damage occur; death likely.
10,000 milliamperes	Cardiac arrest, severe burns; death probable

* If the extensor muscles are excited by the shock, the person may be thrown away from the power source.

Source: W.B. Kouwenhoven, "Human Safety and Electric Shock," *Electrical Safety Practices*, Monograph, 112, Instrument Society of America, p. 93. November 1968.

What kind of burns can a shock cause?

Burns are the most common shock-related injury. An electrical accident can result in an electrical burn, arc burn, thermal contact burn, or a combination of burns.

Electrical burns are among the most serious burns and require immediate medical attention. They occur when electric current flows through tissues or bone, generating heat that causes tissue damage.

Arc or flash burns result from high temperatures caused by an electric arc or explosion near the body. These burns should be treated promptly.

Thermal contact burns are caused when the skin touches hot surfaces of overheated electric conductors, conduits, or other energized equipment. Thermal burns also can be caused when clothing catches on fire, as may occur when an electric arc is produced.

In addition to shock and burn hazards, electricity poses other dangers. For example, arcs that result from short circuits can cause injury or start a fire. Extremely high-energy arcs can damage equipment, causing fragmented metal to fly in all directions. Even low-energy arcs can cause violent explosions in atmospheres that contain flammable gases, vapors, or combustible dusts.

Why do people sometimes "freeze" when they are shocked?

When a person receives an electrical shock, sometimes the electrical stimulation causes the muscles to contract. This "freezing" effect makes the person unable to pull free of the circuit. It is extremely dangerous because it increases the length of exposure to electricity and because the current causes blisters, which reduce the body's resistance and increases the current.

The longer the exposure, the greater the risk of serious injury. Longer exposures at even relatively low voltages can be just as dangerous as short exposures at higher voltages. Low voltage does not imply low hazard.

In addition to muscle contractions that cause "freezing," electrical shocks also can cause involuntary muscle reactions. These reactions can result in a wide range of other injuries from collisions or falls, including bruises, bone fractures, and even death.

What should you do if someone "freezes" to a live electrical contact?

If a person is "frozen" to a live electrical contact, shut off the current immediately. If this is not possible, use boards, poles, or sticks made of wood or any other nonconducting materials and safely push or pull the person away from the contact. It's important to act quickly, but remember to protect yourself as well from electrocution or shock.

How can you tell if a shock is serious?

A severe shock can cause considerably more damage than meets the eye. A victim may suffer internal hemorrhages and destruction of tissues, nerves, and muscles that aren't readily visible. Renal damage also can occur. If you or a coworker receives a shock, seek emergency medical help immediately.

What is the danger of static electricity?

Static electricity also can cause a shock, though in a different way and generally not as potentially severe as the type of shock described previously. Static electricity can build up on the surface of an object and, under the right conditions, can discharge to a person, causing a shock. The most familiar example of this is when a person reaches for a door knob or other metal object on a cold, relatively dry day and receives a shock.

However, static electricity also can cause shocks or can just discharge to an object with much more serious consequences, as when friction causes a high level of static electricity to build up at a specific spot on an object. This can happen simply through handling plastic pipes and materials or during normal operation of rubberized drive or machine belts found in many worksites. In these cases, for example, static electricity can potentially discharge when sufficient amounts of flammable or combustible substances are located nearby and cause an explosion. Grounding or other measures may be necessary to prevent this static electricity buildup and the results.

Protection Against Electrical Hazards

What is the best way to protect yourself against electrical hazards?

Most electrical accidents result from one of the following three factors:

- unsafe equipment or installation,
- unsafe environment, or
- unsafe work practices.

Some ways to prevent these accidents are through the use of insulation, guarding, grounding, electrical protective devices, and safe work practices.

What protection does insulation provide?

Insulators such as glass, mica, rubber, or plastic used to coat metals and other conductors help stop or reduce the flow of electrical current. This helps prevent shock, fires, and short circuits. To be effective, the insulation must be suitable for the voltage used and conditions such as temperature and other environmental factors like moisture, oil, gasoline, corrosive fumes, or other substances that could cause the insulator to fail.

How do you identify different types of insulation?

Insulation on conductors is often color coded. Insulated equipment grounding conductors usually are either solid green or green with yellow stripes. Insulation covering grounded conductors is generally white or gray. Ungrounded conductors, or "hot wires," often are black or red, although they may be any color other than green, white, or gray.

Before connecting electrical equipment to a power source, it's a good idea to check the insulation for any exposed wires for possible defects. Insulation covering flexible cords such as extension cords is particularly vulnerable to damage.

The insulation that covers conductors in non-construction applications is regulated by Subpart S of *29 CFR* 1910.302 through 1910.308, *Wiring Design and Protection.* Subpart S generally requires insulation on circuit conductors. It also specifies that the insulation used should be suitable for the voltage and conditions. Conductors used in construction applications are regulated by Subpart K of *29 CFR* 1926.402 through 1926.408.

What is guarding and what protection does it offer?

Guarding involves locating or enclosing electric equipment to make sure people don't accidentally come into contact with its live parts. Effective guarding requires equipment with exposed parts operating at 50 volts or more to be placed where it is accessible only to authorized people qualified to work with it. Recommended locations are a room, vault, or similar enclosure; a balcony, gallery, or elevated platform; or a site elevated 8 feet (2.44 meters) or more above the floor. Sturdy, permanent screens also can serve as effective guards.

Conspicuous signs must be posted at the entrances to electrical rooms and similarly guarded locations to alert people to the electrical hazard and to forbid entry to unauthorized people. Signs may contain the word "Danger," "Warning," or "Caution," and beneath that, appropriate concise wording that alerts people to the hazard or gives an instruction, such as "Danger/High Voltage/Keep Out."

What is grounding and what protection does it offer?

"Grounding" a tool or electrical system means intentionally creating a low-resistance path that connects to the earth. This prevents the buildup of voltages that could cause an electrical accident.

Grounding is normally a secondary protective measure to protect against electric shock. It does not guarantee that you won't get a shock or be injured or killed by an electrical current. It will, however, substantially reduce the risk, especially when used in combination with other safety measures discussed in this booklet.

29 CFR, Part 1910.304, Subpart S, *Wiring Design and Protection,* requires at times a service or system ground and an equipment ground in non-construction applications.

A *service* or *system ground* is designed primarily to protect machines, tools, and insulation against damage. One wire, called the "neutral" or "grounded" conductor, is grounded. In an ordinary low-voltage circuit, the white or gray wire is grounded at the generator or transformer and at the building's service entrance.

An *equipment ground* helps protect the equipment operator. It furnishes a second path for the current to pass through from the tool or machine to the ground. This additional ground safeguards the operator if a malfunction causes the tool's metal frame to become energized. The resulting flow of current may activate the circuit protection devices.

What are circuit protection devices and how do they work?

Circuit protection devices limit or stop the flow of current automatically in the event of a ground fault, overload, or short circuit in the wiring system. Well-known examples of these devices are fuses, circuit breakers, ground-fault circuit interrupters, and arc-fault circuit interrupters.

Fuses and *circuit breakers* open or break the circuit automatically when too much current flows through them. When that happens, fuses melt and circuit breakers trip the circuit open. Fuses and circuit breakers are designed to protect conductors and equipment. They prevent wires and other components from overheating and open the circuit when there is a risk of a ground fault.

G*round-fault circuit interrupters*, or GFCIs, are used in wet locations, construction sites, and other high-risk areas. These devices interrupt the flow of electricity within as little as 1/40 of a second to prevent electrocution. GFCIs compare the amount of current going into electric equipment with the amount of current returning from it along the circuit conductors. If the difference exceeds 5 milliamperes, the device automatically shuts off the electric power.

Arc-fault devices provide protection from the effects of arc-faults by recognizing characteristics unique to arcing and by functioning to deenergize the circuit when an arc-fault is detected.

What work practices help protect you against electrical hazards?

Electrical accidents are largely preventable through safe work practices. Examples of these practices include the following:

- deenergizing electric equipment before inspection or repair,
- keeping electric tools properly maintained,
- exercising caution when working near energized lines, and
- using appropriate protective equipment.

Electrical safety-related work practice requirements for general industry are detailed in Subpart S of *29 CFR* Part 1910, in Sections 1910.331–1910.335. For construction applications, electrical safety-related work practice requirements are detailed in Subpart K of *29 CFR* Part 1926.416 to 1926.417.

How can you protect yourself against metal parts that become energized?

A break in an electric tool's or machine's insulation can cause its metal parts to become "hot" or energized, meaning that they conduct electricity. Touching these energized parts can result in an electrical shock, burn, or electrocution. The best way to protect yourself when using electrical tools or machines is to establish a low-resistance path from the device's metallic case to the ground. This requires an equipment grounding conductor, a low-resistance wire that directs unwanted current directly to the ground. A properly installed grounding conductor has a low resistance to ground and greatly reduces the amount of current that passes through your body. Cord and plug equipment with a three-prong plug is a common example of equipment incorporating this ground conductor.

Another form of protection is to use listed or labeled portable tools and appliances protected by an approved system of double insulation or its equivalent. Where such a system is employed, it must be marked distinctively to indicate that the tool or appliance uses an approved double insulation system.

How can you prevent an accidental or unexpected equipment startup?

Proper lockout/tagout procedures protect you from the dangers of the accidental or unexpected startup of electrical equipment and are required for general industry by OSHA Standard 1910.333, *Selection and Use of Work Practices*. Requirements for construction applications are in *29 CFR* 1926.417, *Lockout and Tagging of Circuits*. These procedures ensure that electrical equipment is deenergized before it is repaired or inspected and protects you against electrocution or shock.

The first step before beginning any inspection or repair job is to turn the current off at the switch box and padlock the switch in the OFF position. This applies even on so-called low-voltage circuits. Securely tagging the switch or controls of the machine or equipment being locked out of service clarifies to everyone in the area which equipment or circuits are being inspected or repaired.

Only qualified electricians who have been trained in safe lockout procedures should maintain electrical equipment. No two of the locks used should match, and each key should fit just one lock. In addition, one individual lock and key should be issued to each maintenance worker authorized to lock out and tag the equipment. All employees who repair a given piece of equipment should lock out its switch with an individual lock. Only authorized workers should be permitted to remove it.

How can you protect yourself from overhead power lines?

Before working under or near overhead power lines, ensure that you maintain a safe distance to the lines and, for very high-voltage lines, ground any equipment such as cranes that can become energized. If working on power lines, ensure that the lines have been deenergized and grounded by the owner or operator of the lines. Other protective measures like guarding or insulating the lines help prevent accidental contact.

Employees unqualified to work with electricity, as well as mechanical equipment, should remain at least 10 feet (3.05 meters) away from overhead power lines. If the voltage is more than 50,000 volts, the clearance increases by 4 inches (10 centimeters) for each additional 10,000 volts.

When mechanical equipment is operated near overhead lines, employees standing on the ground should avoid contact with the equipment unless it is located outside the danger zone. When factoring the safe standoff distance, be sure to consider the equipment's maximum reach.

What protection does personal equipment offer?

Employees who work directly with electricity should use the personal protective equipment required for the jobs they perform. This equipment may include rubber insulating gloves, hoods, sleeves, matting, blankets, line hose, and industrial protective helmets designed to reduce electric shock hazard. All help reduce the risk of electrical accidents.

What role do tools play?

Appropriate and properly maintained tools help protect workers against electric hazards. It's important to maintain tools regularly because it prevents them from deteriorating and becoming dangerous. Check each tool before using it. If you find a defect, immediately remove it from service and tag it so no one will use it until it has been repaired or replaced.

When using a tool to handle energized conductors, check to make sure it is designed and constructed to withstand the voltages and stresses to which it has been exposed.

What special training do employees need?

All employees should be trained to be thoroughly familiar with the safety procedures for their particular jobs. Moreover, good judgment and common sense are integral to preventing electrical accidents. When working on electrical equipment, for example, some basic procedures to follow are to:

- deenergize the equipment,
- use lockout and tag procedures to ensure that the equipment remains deenergized,
- use insulating protective equipment, and
- maintain a safe distance from energized parts.

What's the value of a safety and health program in controlling electrical hazards?

Every good safety and health program provides measures to control electrical hazards. The measures suggested in this booklet should be helpful in establishing such a program. The responsibility for this program should be delegated to someone with a complete knowledge of electricity, electrical work practices, and the appropriate OSHA standards for installation and performance.

Everyone has the right to work in a safe environment. Safety and health add value to your business and your workplace. Through cooperative efforts, employers and employees can learn to identify and eliminate or control electrical hazards.

How Can OSHA Help Me?

OSHA can provide extensive help through a variety of programs, including assistance about safety and health programs, state plans, workplace consultations, voluntary protection programs, strategic partnerships, training and education, and more.

How does safety and health program management assistance help employers and employees?

Working in a safe and healthful environment can stimulate innovation and creativity and result in increased performance and higher productivity.

To assist employers and employees in developing effective safety and health programs, OSHA published recommended *Safety and Health Program Management Guidelines* (*Federal Register* 54(18):3904–3916, January 26, 1989). These voluntary guidelines can be applied to all worksites covered by OSHA.

The guidelines identify four general elements that are critical to the development of a successful safety and health management system:

- management leadership and employee involvement,
- worksite analysis,
- hazard prevention and control, and
- safety and health training.

The guidelines recommend specific actions under each of these general elements to achieve an effective safety and health program. The *Federal Register* notice is available online at www.osha.gov.

What are state plans?

State plans are OSHA-approved job safety and health programs operated by individual states or territories instead of Federal OSHA. The *Occupational Safety and Health Act of 1970* (*OSH Act*) encourages states to develop and operate their own job safety and health plans and permits state enforcement of OSHA standards if the state has an approved plan. Once OSHA approves a state plan, it funds 50 percent of the program's operating costs. State plans must provide standards and enforcement programs, as well as voluntary compliance activities, that are at least as effective as those of Federal OSHA.

There are 26 state plans: 23 cover both private and public (state and local government) employment, and 3 (Connecticut, New Jersey, and New York) cover only the public sector. For more information on state plans, see the listing at the end of this publication, or visit OSHA's website at www.osha.gov.

How can consultation assistance help employers?

In addition to helping employers identify and correct specific hazards, OSHA's consultation service provides free, onsite assistance in developing and implementing effective workplace safety and health management systems that emphasize the prevention of worker injuries and illnesses.

Comprehensive consultation assistance provided by OSHA includes a hazard survey of the worksite and an appraisal of all aspects of the employer's existing safety and health management system. In addition, the service offers assistance to employers in developing and implementing an effective safety and health management system. Employers also may receive training and education services, as well as limited assistance away from the worksite.

Who can get consultation assistance and what does it cost?

Consultation assistance is available to small employers (with fewer than 250 employees at a fixed site and no more than 500 corporatewide) who want help in establishing and maintaining a safe and healthful workplace.

Funded largely by OSHA, the service is provided at no cost to the employer. Primarily developed for smaller employers with more hazardous operations, the consultation service is delivered by state governments employing professional safety and health consultants. No penalties are proposed or citations issued for hazards identified by the consultant. The employer's only obligation is to correct all identified serious hazards within the agreed-upon correction time frame.

Can OSHA assure privacy to an employer who asks for consultation assistance?

OSHA provides consultation assistance to the employer with the assurance that his or her name and firm and any information about the workplace will not be routinely reported to OSHA enforcement staff.

Can an employer be cited for violations after receiving consultation assistance?

If an employer fails to eliminate or control a serious hazard within the agreed-upon time frame, the consultation project manager must refer the situation to the OSHA enforcement office for appropriate action. This is a rare occurrence, however, because employers request the service for the expressed purpose of identifying and fixing hazards in their workplaces.

Does OSHA provide any incentives for seeking consultation assistance?

Yes. Under the consultation program, certain exemplary employers may request participation in OSHA's Safety and Health Achievement Recognition Program (SHARP). Eligibility for participation in SHARP includes, but is not limited to, receiving a full-service, comprehensive consultation visit, correcting all identified hazards, and developing an effective safety and health management system.

Employers accepted into SHARP may receive an exemption from programmed inspections (not complaint or accident investigation inspections) for a period of 1 year initially, or 2 years upon renewal. For more information concerning consultation assistance, see the consultation directory at the end of this publication, contact your regional or area OSHA office, or visit OSHA's website at www.osha.gov.

What is the Voluntary Protection Program?

Voluntary Protection Programs (VPPs) represent one part of OSHA's effort to extend worker protection beyond the minimum required by OSHA standards. VPP — along with onsite consultation services, full-service area offices, and OSHA's Strategic Partnership Program (OSPP) — represents a cooperative approach which, when coupled with an effective enforcement program, expands worker protection to help meet the goals of the *OSH Act.*

How does the Voluntary Protection Program work?

There are three levels of VPPs: Star, Merit, and Demonstration. All are designed to do the following:

- recognize employers who have successfully developed and implemented effective and comprehensive safety and health management systems;
- encourage these employers to continuously improve their safety and health management systems;
- motivate other employers to achieve excellent safety and health results in the same outstanding way; and
- establish a relationship between employers, employees, and OSHA that is based on cooperation.

How does VPP help employers and employees?

VPP participation can mean the following:

- reduced numbers of worker fatalities, injuries, and illnesses;
- lost-workday case rates generally 50 percent below industry averages;
- lower workers' compensation and other injury- and illness-related costs;
- improved employee motivation to work safely, leading to a better quality of life at work;
- positive community recognition and interaction;
- further improvement and revitalization of already good safety and health programs; and
- a positive relationship with OSHA.

How does OSHA monitor VPP sites?

OSHA reviews an employer's VPP application and conducts a VPP onsite evaluation to verify that the safety and health management systems described are operating effectively at the site. OSHA conducts onsite evaluations on a regular basis, annually for participants at the Demonstration level, every 18 months for Merit, and every 3 to 5 years for Star. Each February, all participants must send a copy of their most recent annual evaluation to their OSHA regional office. This evaluation must include the worksite's record of injuries and illnesses for the past year.

Can OSHA inspect an employer who is participating in the VPP?

Sites participating in VPP are not scheduled for regular, programmed inspections. OSHA handles any employee complaints, serious accidents, or significant chemical releases that may occur at VPP sites according to routine enforcement procedures.

Additional information on VPP is available from OSHA national, regional, and area offices, listed at the end of this booklet. Also, see **Outreach** on OSHA's website at www.osha.gov.

How can a partnership with OSHA improve worker safety and health?

OSHA has learned firsthand that voluntary, cooperative partnerships with employers, employees, and unions can be a useful alternative to traditional enforcement and an effective way to reduce worker deaths, injuries, and illnesses. This is especially true when a partnership leads to the development and implementation of comprehensive workplace safety and health management system.

What is OSHA's Strategic Partnership Program (OSPP)?

OSHA Strategic Partnerships are alliances among labor, management, and government to foster improvements in workplace safety and health. These partnerships are voluntary, cooperative relationships between OSHA, employers, employee representatives, and others such as trade unions, trade and professional associations, universities, and other government agencies. OSPPs are the newest member of OSHA's family of cooperative programs.

What do OSPPs do?

These partnerships encourage, assist, and recognize the efforts of the partners to eliminate serious workplace hazards and achieve a high level of worker safety and health. Whereas OSHA's Consultation Program and VPP entail one-on-one relationships between OSHA and individual worksites, most strategic partnerships seek to have a broader impact by building cooperative relationships with groups of employers and employees.

Are there different kinds of OSPPs?

There are two major types:

- comprehensive, which focus on establishing comprehensive safety and health management systems at partnering worksites; and
- limited, which help identify and eliminate hazards associated with worker deaths, injuries, and illnesses, or have goals other than establishing comprehensive worksite safety and health programs.

OSHA is interested in creating new OSPPs at the national, regional, and local levels. OSHA also has found limited partnerships to be valuable. Limited partnerships might address the elimination or control of a specific industry hazard.

What are the benefits of participation in the OSPP?

Like VPP, OSPP can mean the following:

- fewer worker fatalities, injuries, and illnesses;
- lower workers' compensation and other injury- and illness-related costs;
- improved employee motivation to work safely, leading to a better quality of life at work and enhanced productivity;
- positive community recognition and interaction;
- development of or improvement in safety and health management systems; and
- positive interaction with OSHA.

For more information about this program, contact your nearest OSHA office or go to the agency website at www.osha.gov.

Does OSHA have occupational safety and health training for employers and employees?

Yes. The OSHA Training Institute in Des Plaines, IL, provides basic and advanced training and education in safety and health for federal and state compliance officers, state consultants, other federal agency personnel, and private-sector employers, employees, and their representatives.

Institute courses cover diverse safety and health topics including electrical hazards, machine guarding, personal protective equipment, ventilation, and ergonomics. The facility includes classrooms, laboratories, a library, and an audiovisual unit. The laboratories contain various demonstrations and equipment, such as power presses, woodworking and welding shops, a complete industrial ventilation unit, and a sound demonstration laboratory. More than 57 courses dealing with subjects such as safety and health in the construction industry and methods of compliance with OSHA standards are available for personnel in the private sector.

In addition, OSHA's 73 area offices are full-service centers offering a variety of informational services such as personnel for speaking engagements, publications, audiovisual aids on workplace hazards, and technical advice.

For more information on grants, training, and education, write: OSHA Training Institute, Office of Training and Education, 1555 Times Drive, Des Plaines, IL 60018; call (847) 297–4810; or see **Outreach** on OSHA's website at www.osha.gov.

Does OSHA give money to organizations for training and education?

OSHA awards grants through its Susan Harwood Training Grant Program to nonprofit organizations to provide safety and health training and education to employers and workers in the workplace. The grants focus on programs that will educate workers and employers in small business (fewer than 250 employees), training workers and employers about new OSHA standards or about high-risk activities or hazards. Grants are awarded for 1 year and may be renewed for an additional 12 months depending on whether the grantee has performed satisfactorily.

OSHA expects each organization awarded a grant to develop a training and/or education program that addresses a safety and health topic named by OSHA, recruit workers and employers for the training, and conduct the training. Grantees are also expected to follow up with people who have been trained to find out what changes were made to reduce the hazards in their workplaces as a result of the training.

Each year OSHA has a national competition that is announced in the *Federal Register* and on the Internet at www.osha-slc.gov/Training/sharwood/sharwood.html. If you do not have access to the Internet, you can contact the OSHA Office of Training and Education, 1555 Times Drive, Des Plaines, Illinois 60018, (847) 297–4810, for more information.

Does OSHA have other assistance materials available?

OSHA has a variety of materials and tools available on its website at www.osha.gov. These include e-Tools such as Expert Advisors and Electronic Compliance Assistance Tools (e-CATs), Technical Links, regulations, directives, publications, videos, and other information for employers and employees. OSHA's software programs and compliance assistance tools walk you through challenging safety and health issues and common problems to find the best solutions for your workplace. OSHA's comprehensive publications program includes more than 100 titles to help you understand OSHA requirements and programs.

OSHA's CD-ROM includes standards, interpretations, directives, and more and can be purchased on CD-ROM from the U.S. Government Printing Office. To order, write to the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402, or phone (202) 512–1800. Specify OSHA Regulations, Documents and Technical Information on CD-ROM (ORDT), GPO Order No. S/N 729-013-00000-5.

What do I do in case of an emergency? Or if I need to file a complaint?

To report an emergency, file a complaint, or seek OSHA advice, assistance, or products, call (800) 321–OSHA or contact your nearest OSHA regional or area office listed at the end of this publication. The teletypewriter (TTY) number is (877) 889–5627.

You can also file a complaint online and obtain more information on OSHA federal and state programs by visiting OSHA's website at www.osha.gov.

OSHA Offices

OSHA Regional Offices

Region I
(CT,* ME, MA, NH, RI, VT*)
JFK Federal Building, Room E340
Boston, MA 02203
(617) 565-9860

Region II
(NJ,* NY,* PR,* VI*)
201 Varick Street, Room 670
New York, NY 10014
(212) 337-2378

Region III
(DE, DC, MD,* PA,* VA,* WV)
The Curtis Center
170 S. Independence Mall West
Suite 740 West
Philadelphia, PA 19106-3309
(215) 861-4900

Region IV
(AL, FL, GA, KY,* MS, NC,* SC,* TN*)
SNAF
61 Forsyth Street SW, Room 6T50
Atlanta, GA 30303
(404) 562-2300

Region V
(IL, IN,* MI,* MN,* OH, WI)
230 South Dearborn Street, Room 3244
Chicago, IL 60604
(312) 353-2220

Region VI
(AR, LA, NM,* OK, TX)
525 Griffin Street, Room 602
Dallas, TX 75202
(214) 767-4731 or 4736 x224

Region VII
(IA,* KS, MO, NE)
City Center Square
1100 Main Street, Suite 800
Kansas City, MO 64105
(816) 426-5861

Region VIII
(CO, MT, ND, SD, UT,* WY*)
1999 Broadway, Suite 1690
PO Box 46550
Denver, CO 80202-5716
(303) 844-1600

Region IX
(American Samoa, AZ,* CA,* HI, NV,* Northern Mariana Islands)
71 Stevenson Street, Room 420
San Francisco, CA 94105
(415) 975-4310

Region X
(AK,* ID, OR,* WA*)
1111 Third Avenue, Suite 715
Seattle, WA 98101-3212
(206) 553-5930

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* These states and territories operate their own OSHA-approved job safety and health programs. (Connecticut, New Jersey and New York plans cover public employees only.) States with approved programs must have a standard that is identical to, or at least as effective as, the federal standard.

OSHA Area Offices

Alabama

U.S. Department of Labor—OSHA
Vestavia Village, 2047 Canyon Road
Birmingham, AL 35216–1981
(205) 731-1534

U.S. Department of Labor—OSHA
3737 Government Boulevard, Suite 100
Mobile, AL 36693-4309
(251) 441-6131

Alaska

U.S. Department of Labor—OSHA
301 W. Northern Lights Blvd, Suite 407
Anchorage, AK 99503
(907) 271-5152

Arizona

U.S. Department of Labor—OSHA
3221 North 16th Street, Suite 100
Phoenix, AZ 85016
(602) 640-2348

Arkansas

U.S. Department of Labor—OSHA
TCBY Building, Suite 450
425 West Capitol Avenue
Little Rock, AR 72201
(501) 324-6291(5818)

California

U.S. Department of Labor—OSHA
5675 Ruffin Road, Suite 330
San Diego, CA 92123
(619) 557-5909

U.S. Department of Labor—OSHA
101 El Camino Plaza, Suite 105
Sacramento, CA 95815
(916) 566-7471

Colorado

U.S. Department of Labor—OSHA
1391 Speer Boulevard, Suite 210
Denver, CO 80204-2552
(303) 844-5285

U.S. Department of Labor—OSHA
7935 East Prentice Avenue, Suite 209
Greenwood Village, CO 80111-2714
(303) 843-4500

Connecticut

U.S. Department of Labor—OSHA
1057 Broad Street, Fourth Floor
Bridgeport, CT 06604
(203) 579-5581

U.S. Department of Labor—OSHA
Federal Building
450 Main Street, Room 613
Hartford, CT 06103
(860) 240-3152

Delaware

U.S. Department of Labor—OSHA
Caleb Boggs Federal Building
844 N King Street, Room 2209
Wilmington, DE 19801-3319
(302) 573-6518

Florida

U.S. Department of Labor—OSHA
8040 Peters Road, Building H-100
Fort Lauderdale, FL 33324
(954) 424-0242

U.S. Department of Labor—OSHA
Ribault Building, Suite 227
1851 Executive Center Drive
Jacksonville, FL 32207
(904) 232-2895

U.S. Department of Labor—OSHA
5807 Breckenridge Parkway, Suite A
Tampa, FL 33610-4249
(813) 626-1177

Georgia

U.S. Department of Labor—OSHA
450 Mall Boulevard, Suite J
Savannah, GA 31406
(912) 652-4393

U.S. Department of Labor—OSHA
2400 Herodian Way, Suite 250
Smyrna, GA 30080-2968
(770) 984-8700

U.S. Department of Labor—OSHA
LaVista Perimeter Office Park
2183 N. Lake Parkway
Building 7, Suite 110
Tucker, GA 30084-4154
(770) 493-6644/6742/8419

Idaho

U.S. Department of Labor—OSHA
1150 North Curtis Road, Suite 201
Boise, ID 83706
(208) 321-2960

Illinois

U.S. Department of Labor—OSHA
1600 167th Street, Suite 9
Calumet City, IL 60409
(708) 891-3800

U.S. Department of Labor—OSHA
O'hara Plaza
701 Lee Street, Suite #950
Des Plaines, IL 60016
(847) 803-4800

U.S. Department of Labor—OSHA
11 Executive Drive, Suite 11
Fairview Heights, IL 62208
(618) 632-8612

U.S. Department of Labor—OSHA
365 Smoke Tree Business Park
North Aurora, IL 60542
(630) 896-8700

U.S. Department of Labor—OSHA
2918 West Willow Knolls Road
Peoria, IL 61614
(309) 671-7033

Indiana

U.S. Department of Labor—OSHA
46 East Ohio Street, Room 453
Indianapolis, IN 46204
(317) 226-7290

Iowa

U.S. Department of Labor—OSHA
210 Walnut Street, Room 815
Des Moines, IA 50309
(515) 284-4794

Kansas

U.S. Department of Labor—OSHA
217 W. 3rd Street North
Room #400
Wichita, KS 67202
(316) 269-6644

Kentucky

U.S. Department of Labor—OSHA
John C. Watts Federal Building
330 W. Broadway, Room 108
Frankfort, KY 40601-1922
(502) 227-7024

Louisiana

U.S. Department of Labor—OSHA
9100 Bluebonnet Centre Boulevard
Suite 201
Baton Rouge, LA 70809
(225) 389-0474 (0431)

Maine

U.S. Department of Labor—OSHA
202 Harlow Street, Room 211
Bangor, ME 04401
(207) 941-8177

U.S. Department of Labor—OSHA
West Tower
100 Middle Street, Suite 410 West
Portland, ME 04101
(207) 780-3178

Maryland

U.S. Department of Labor—OSHA
1099 Winterson Road, Suite 140
Linthicum, MD 21090-2218
(410) 865-2055/2056

Massachusetts

U.S. Department of Labor—OSHA
639 Granite Street, 4th Floor
Braintree, MA 02184
(617) 565-6924

U.S. Department of Labor—OSHA
Valley Office Park
13 Branch Street
Methuen, MA 01844
(617) 565-8110

U.S. Department of Labor—OSHA
1441 Main Street, Room 550
Springfield, MA 01103-1493
(413) 785-0123

Michigan

U.S. Department of Labor—OSHA
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Minnesota

U.S. Department of Labor—OSHA
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Mississippi

U.S. Department of Labor—OSHA
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Missouri

U.S. Department of Labor—OSHA
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Kansas City, MO 64120
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U.S. Department of Labor—OSHA
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Billings, MT 59101
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Nebraska

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Overland–Wolf Building
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Omaha, NE 68106
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Nevada

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New Hampshire

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New Jersey

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Plaza 35, Suite 205
Avenel, NJ 07001
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U.S. Department of Labor—OSHA
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Hasbrouck Heights, NJ 07604
(201) 288-1700

U.S. Department of Labor—OSHA
Marlton Executive Park, Building 2
701 Route 73 South, Suite 120
Marlton, NJ 08053
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Parsippany, NJ 07054
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Bayside, NY 11361
(718) 279–9060

U.S. Department of Labor—OSHA
5360 Genesee Street
Bowmansville, NY 14026
(716) 684-3891

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201 Varick Street, Room #646
New York, NY 10014
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(914) 524-7510

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300 Fayetteville Street Mall, Room 438
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North Dakota

U.S. Department of Labor—OSHA
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Bismark, ND 58501
(701) 250-4521

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Cincinnati, OH 45246
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U.S. Department of Labor—OSHA
Federal Office Building
1240 East 9th Street, Room 899
Cleveland, OH 44199
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200 North High Street, Room 620
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U.S. Department of Labor—OSHA
420 Madison Avenue
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Toledo, OH 43604
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U.S. Department of Labor—OSHA
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Oklahoma City, OK 73102-9237
(405) 278-9560

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3939 West Ridge Road, Suite B12
Erie, PA 16506-1887
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Harrisburg, PA 17109
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Philadelphia, PA 19106-2902
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Wilkes-Barre, PA 18702-350
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Columbia, SC 29201-2453
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(615) 781-5423

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606 N. Carancahua, Suite 700
Corpus Christi, TX 78476
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U.S. Department of Labor—OSHA
8344 East R.L. Thornton Freeway, Suite 420
Dallas, TX 75228
(214) 320-2400 (2558)

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700 E San Antonio St.
Room C-408
El Paso, TX 79901
(915) 534-6251

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8713 Airport Freeway
Fort Worth, TX 76180-7610
(817) 428-2470 (485-7647)

U.S. Department of Labor—OSHA
507 N. Sam Houston Parkway, Suite 400
Houston, TX 77060
(281) 591-2438 (2787)

U.S. Department of Labor—OSHA
17625 El Camino Real, Suite 400
Houston, TX 77058
(281) 286-0583/0584 (5922)

U.S. Department of Labor—OSHA
Federal Office Building
1205 Texas Avenue, Room 806
Lubbock, TX 79401
(806) 472-7681 (7685)

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160 E 300 South
Heber-Wells Building
P. O. Box 146650
Salt Lake City, UT 84114-6650
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U.S. Department of Labor—OSHA
Federal Office Building
200 Granby Street, Room 614
Norfolk, VA 23510
(757) 441-3820

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U.S. Department of Labor—OSHA
505 106th Avenue, NE, Suite 302
Bellevue, WA 98004
(206) 553-7520

West Virginia

U.S. Department of Labor—OSHA
405 Capitol Street
Suite 407
Charleston, WV 25301
(304) 347-5937

Wisconsin

U.S. Department of Labor—OSHA
1648 Tri Parkway
Appleton, WI 54914
(920) 734-4521

U.S. Department of Labor—OSHA
1310 West Clairmont Avenue
Eau Claire, WI 54701
(715) 832-9019

U.S. Department of Labor—OSHA
4802 E. Broadway
Madison, WI 53716
(608) 264-5388

U.S. Department of Labor—OSHA
Henry S. Reuss Building
310 W. Wisconsin Ave, Suite 1180
Milwaukee, WI 53203
(414) 297-3315

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* For issues involving federal agencies or private companies working for federal agencies in Arizona, California, Guam, Hawaii, and Nevada, call the numbers listed. For issues involving private or state government employers in these states, refer to the appropriate state office in Arizona, California, Hawaii, and Nevada.

States and Territories with OSHA-Approved Safety and Health Plans

Alaska

Commissioner
Alaska Department of Labor
1111 W. 8th Street, Room 308
P.O. Box 21149
Juneau, AK 99802-1149
(907) 465-2700

Arizona

Director
Industrial Commission of Arizona
800 W. Washington
Phoenix, AZ 85007
(602) 542-5795

California

Director
California Department of Industrial Relations
455 Golden Gate Avenue, 10th floor
San Francisco, CA 94102
(415) 703-5050

Connecticut

Commissioner
Connecticut Department of Labor
200 Folly Brook Boulevard
Wethersfield, CT 06109
(860) 263-6505

Hawaii

Director
Hawaii Department of Labor and Industrial Relations
830 Punchbowl Street
Honolulu, HI 96831
(808) 586-8844

Indiana

Commissioner
Indiana Department of Labor
State Office Building
402 West Washington Street, Room W195
Indianapolis, IN 46204
(317) 232-2378

Iowa

Commissioner
Iowa Division of Labor
1000 E. Grand Avenue
Des Moines, IA 50319
(515) 281-3447

Kentucky

Secretary
Kentucky Labor Cabinet
1047 U.S. Highway 127 South, Suite 4
Frankfort, KY 40601
(502) 564-3070

Maryland

Commissioner
Maryland Division of Labor and Industry
Department of Labor Licensing and Regulation
MOSH
1100 N. Eutaw Street, Room 613
Baltimore, MD 21201-2206
(410) 767-2215

Michigan

Director
Michigan Department of Consumer and Industry Services
P.O. Box 30643
7150 Harris Drive
Lansing, MI 48909
(517) 373-7230

Minnesota

Commissioner
Minnesota Department of Labor and Industry
443 Lafayette Road
St. Paul, MN 55155
(651) 284-5010

Nevada

Administrator
Nevada Division of Industrial Relations
400 West King Street, Suite 400
Carson City, NV 89703
(775) 684-7260

New Jersey

Commissioner
New Jersey Department of Labor
John Fitch Plaza — Labor Building
Market and Warren Streets
P.O. Box 110
Trenton, NJ 08625-0110
(609) 292-2975

New Mexico

Secretary
New Mexico Environment Department
1190 St. Francis Drive
P.O. Box 26110
Santa Fe, NM 87502
(505) 827-2850

New York

Commissioner
New York Department of Labor
W. Averell Harriman State Office
Building-12, Room 500
Albany, NY 12240
(518) 457-2741

North Carolina

Commissioner
North Carolina Department of Labor
4 West Edenton Street
Raleigh, NC 27601-1092
(919) 807-2900

Oregon

Administrator
Oregon Department of Consumer and Business Services
Occupational Safety and Health Division (OR-OSHA)
350 Winter Street, N.E. Room 430
Salem, OR 97310-3882
(503) 378-3272

Puerto Rico

Secretary
Puerto Rico Department of Labor and Human Resources
Prudencio Rivera Martinez Building
505 Munoz Rivera Avenue
Hato Rey, PR 00918
(787) 754-2119

South Carolina

South Carolina Department of Labor, Licensing and Regulation
Koger Office Park, Kingstree Building
110 Centerview Drive
P.O. Box 11329
Columbia, SC 29211
(803) 896-4300

Tennessee

Commissioner
Tennessee Department of Labor and Workforce Development
710 James Robertson Parkway
Andrew Johnson Tower
Nashville, TN 37243-0659
(615) 741-2582

Utah

Commissioner
Labor Commission of Utah
160 East 300 South Street, 3rd floor
P.O. Box 146650
Salt Lake City, UT 84111
(801) 530-6901

Vermont

Commissioner
Vermont Department of Labor and Industry
National Life Building, Drawer 20
120 State Street
Montpelier VT 05620-3401
(802) 828-2288

Virgin Islands

Commissioner
Virgin Islands Department of Labor
2203 Church Street
Christiansted, St. Croix, VI 00820-4660
(340) 773-1990

Virginia

Commissioner
Virginia Department of Labor and Industry
Powers–Taylor Building
13 South, 13th Street
Richmond, VA 23219
(804) 786-2377

Washington

Director
Washington Department of Labor and Industries
P.O. Box 44001
Olympia, WA 98504-4001
(360) 902-4200 (5430)

Wyoming

Administrator
Worker's Safety and Compensation Division (WSC)
Wyoming Department of Employment
Herschler Building, 2nd Floor East
122 West 25th Street
Cheyenne, WY 82002
(307) 777-7786

OSHA Onsite Consultation Offices

Alabama

Safety State Program University of Alabama
432 Martha Parham West
Post Office Box 870388
Tuscaloosa, AL 35487
(205) 348-3033

Alaska

Consultation Section
ADOL/AKOSH
3301 Eagle Street
Post Office Box 107022
Anchorage, AK 99510-7022
(907) 269-4957

Arizona

Consultation and Training
Division of Occupational Safety & Health
Industrial Commission of Arizona
800 West Washington
Phoenix, AZ 85007-9070
(602) 542-1695

Arkansas

OSHA Consultation
Arkansas Department of Labor
10421 West Markham
Little Rock, AR 72205
(501) 682-4522

California

CAL/OSHA Consultation Service
2424 Arden Way, Suite 410
Sacramento, CA 95825
(916) 263-2856

Colorado

Occupational Safety and Health Section
Colorado State University
133 Environmental Health Building
Fort Collins, CO 80523
(970) 491-6151

Connecticut

Division of Occupational Safety and Health
Connecticut Department of Labor
38 Wolcott Hill Road
Wethersfield, CT 06109
(860) 566-4550

Delaware

Occupational Safety and Health
Division of Industrial Affairs
Delaware Department of Labor
4425 North Market Street
Wilmington, DE 19802
(302) 761-8219

District of Columbia

Office of Occupational Safety and Health
D.C. Dept of Employment Services
950 Upshur Street, N.W.
Washington, DC 20011
(202) 541-3727

Florida

Director of Environmental Safety and Health
Environmental and Occupational Health
College of Public Health
4003 East Fowler Avenue
Tampa, FL 33617
(813) 974-9962

Georgia

Onsite Consultation Program
Georgia Institute of Technology
O'Keefe Building, Room 22
151 6th Street, N.W.
Atlanta, GA 30332-0837
(404) 894-2643

Guam

OSHA Onsite Consultation
Dept. of Labor, Government of Guam
107 F Street
Tiyam, GU 96931
9-1-(671) 475-1101

Hawaii

Consultation and Training Branch
Dept of Labor and Industrial Relations
830 Punchbowl Street
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Idaho

Safety and Health Consultation Program
Boise State University
Safety & Health Consultation Department
1910 University Drive
Boise, ID 83725
(208) 426-3283

Illinois

Illinois Onsite Consultation
Industrial Service Division
Department of Commerce and Community Affairs
State of Illinois Center, Suite 3-400
100 West Randolph Street
Chicago, IL 60601
(312) 814-2337

Indiana

Division of Labor
Bureau of Safety, Education and Training
Room W195
402 West Washington
Indianapolis, IN 46204-2287
(317) 232-2688

Iowa

Iowa Workforce Development Labor Services
Bureau of Consultation and Education
1000 East Grand Avenue
Des Moines, IA 50319
(515) 281-7629

Kansas

21D Consultation Program
Kansas Department of Human Resources
512 South West 6th Street
Topeka, KS 66603-3150
(785) 296-2551

Kentucky

Division of Education and Training
Kentucky Labor Cabinet
1047 U.S. Highway 127, South
Frankfort, KY 40601
(502) 564-6895

Louisiana

7(c)(1) Consultation Program
Louisiana Department of Labor
1001 N. 23rd Street, Room 421
Post Office Box 94040
Baton Rouge, LA 70804-9094
(225) 342-9601

Maine

Division of Industrial Safety
Maine Bureau of Labor Standards
Workplace Safety and Health Division
State House Station #45
Augusta, ME 04333-0045
(207) 624-6400

Maryland

MOSH Consultation Services
Attention: Ms. Colleen Ridler
312 Marshall Avenue Rm 600
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(410) 880-4970

Massachusetts

Division of Occupational Safety and Health
Department of Workforce Development
1001 Watertown Street
West Newton, MA 02165
(617) 727-3982

Michigan

Consultation Education and Training Division
Bureau of Safety and Regulation
Michigan Department of Consumer and Industry Services
7150 Harris Drive, Post Office Box 30643
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Minnesota

Department of Labor and Industry
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443 LaFayette Road North
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(651) 284-5060

Mississippi

Mississippi State University
Center for Safety and Health
106 Crosspark Drive, Suite C
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(601) 939-2047

Missouri

Onsite Consultation Program
Division of Labor Standards
Department of Labor and Industrial Relations
3315 West Truman Boulevard, Room 205
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Montana

Department of Labor and Industry
Bureau of Safety
Post Office Box 1728
Helena, MT 59624-1728
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Nebraska

Division of Safety and Labor Standards
Nebraska Department of Labor
State Office Building, Lower Level
301 Centennial Mall, South
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Nevada

Safety Consultation and Training Section
Division of Industrial Relations
Department of Business and Industry
1301 North Green Valley Parkway
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New Hampshire

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Department of Health and Human Services
Office of Community & Public Health
6 Hazen Drive
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New Jersey

New Jersey Department of Labor
Division of Public Safety and
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CHAPTER 3

DIRECT CURRENT

LEARNING OBJECTIVES

Upon completing this chapter, you will be able to:

1. Identify the term schematic diagram and identify the components in a circuit from a simple schematic diagram.
2. State the equation for Ohm's law and describe the effects on current caused by changes in a circuit.
3. Given simple graphs of current versus power and voltage versus power, determine the value of circuit power for a given current and voltage.
4. Identify the term power, and state three formulas for computing power.
5. Compute circuit and component power in series, parallel, and combination circuits.
6. Compute the efficiency of an electrical device.
7. Solve for unknown quantities of resistance, current, and voltage in a series circuit.
8. Describe how voltage polarities are assigned to the voltage drops across resistors when Kirchhoff's voltage law is used.
9. State the voltage at the reference point in a circuit.
10. Define open and short circuits and describe their effects on a circuit.
11. State the meaning of the term source resistance and describe its effect on a circuit.
12. Describe in terms of circuit values the circuit condition needed for maximum power transfer.
13. Compute efficiency of power transfer in a circuit.
14. Solve for unknown quantities of resistance, current, and voltage in a parallel circuit.
15. State the significance of the polarity assigned to a current when using Kirchhoff's current law.
16. State the meaning of the term equivalent resistance.
17. Compute resistance, current, voltage, and power in voltage dividers.
18. Describe the method by which a single voltage divider can provide both positive and negative voltages.
19. Recognize the safety precautions associated with the hazard of electrical shock.
20. Identify the first aid procedures for a victim of electrical shock.

INTRODUCTION

The material covered in this chapter contains many new terms that are explained as you progress through the material. The basic dc circuit is the easiest to understand, so the chapter begins with the basic circuit and from there works into the basic schematic diagram of that circuit. The schematic diagram is used in all your future work in electricity and electronics. It is very important that you become familiar with the symbols that are used.

This chapter also explains how to determine the total resistance, current, voltage, and power in a series, parallel, or combination circuit through the use of Ohm's and Kirchhoff's laws. The voltage divider network, series, parallel, and series-parallel practice problem circuits will be used for practical examples of what you have learned.

THE BASIC ELECTRIC CIRCUIT

The flashlight is an example of a basic electric circuit. It contains a source of electrical energy (the dry cells in the flashlight), a load (the bulb) which changes the electrical energy into a more useful form of energy (light), and a switch to control the energy delivered to the load.

Before you study a schematic representation of the flashlight, it is necessary to define certain terms. The LOAD is any device through which an electrical current flows and which changes this electrical energy into a more useful form. Some common examples of loads are a lightbulb, which changes electrical energy to light energy; an electric motor, which changes electrical energy into mechanical energy; and the speaker in a radio, which changes electrical energy into sound. The SOURCE is the device which furnishes the electrical energy used by the load. It may consist of a simple dry cell (as in a flashlight), a storage battery (as in an automobile), or a power supply (such as a battery charger). The SWITCH, which permits control of the electrical device, interrupts the current delivered to the load.

SCHEMATIC REPRESENTATION

The technician's main aid in troubleshooting a circuit in a piece of equipment is the SCHEMATIC DIAGRAM. The schematic diagram is a "picture" of the circuit that uses symbols to represent the various circuit components; physically large or complex circuits can be shown on a relatively small diagram. Before studying the basic schematic, look at figure 3-1. This figure shows the symbols that are used in this chapter. These, and others like them, are referred to and used throughout the study of electricity and electronics.

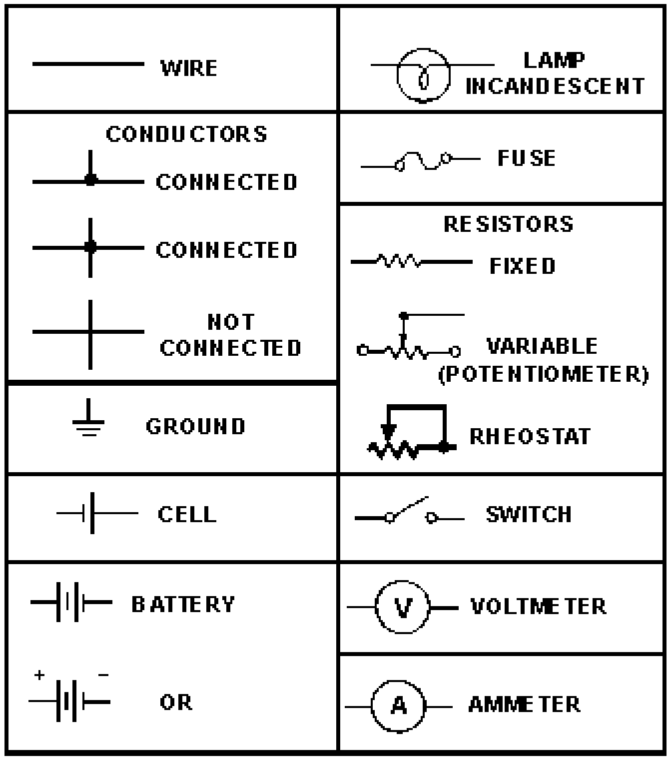


Figure 3-1.—Symbols commonly used in electricity.

The schematic in figure 3-2 represents a flashlight. View A of the figure shows the flashlight in the off or deenergized state. The switch (S1) is open. There is no complete path for current (I) through the circuit, and the bulb (DS1) does not light. In figure 3-2 view B, switch S1 is closed. Current flows in the direction of the arrows from the negative terminal of the battery (BAT), through the switch (S1), through the lamp (DS1), and back to the positive terminal of the battery. With the switch closed the path for current is complete. Current will continue to flow until the switch (S1) is moved to the open position or the battery is completely discharged.

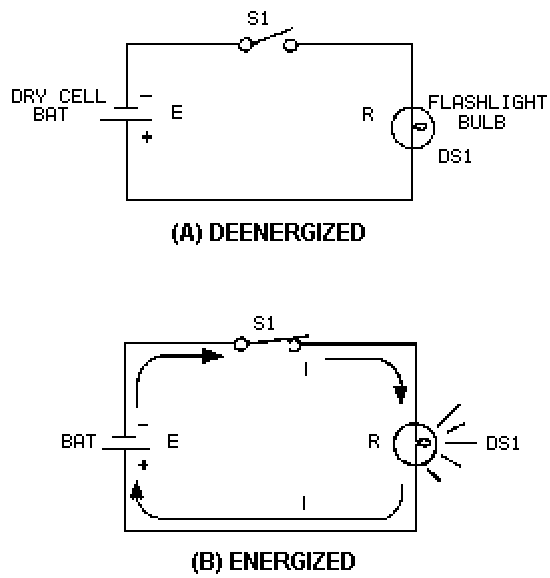


Figure 3-2.—Basic flashlight schematic.

Q1. In figure 3-2, what part of the circuit is the (a) load and (b) source?

Q2. What happens to the path for current when S1 is open as shown in figure 3-2(A)?

Q3. What is the name given to the "picture" of a circuit such as the one shown in figure 3-2?

OHM'S LAW

In the early part of the 19th century, George Simon Ohm proved by experiment that a precise relationship exists between current, voltage, and resistance. This relationship is called Ohm's law and is stated as follows:

The current in a circuit is DIRECTLY proportional to the applied voltage and INVERSELY proportional to the circuit resistance. Ohm's law may be expressed as an equation:

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

Where: I = current in amperes
E = voltage in volts
R = resistance in ohms

As stated in Ohm's law, current is inversely proportional to resistance. This means, as the resistance in a circuit increases, the current decreases proportionately.

In the equation

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

if any two quantities are known, the third one can be determined. Refer to figure 3-2(B), the schematic of the flashlight. If the battery (BAT) supplies a voltage of 1.5 volts and the lamp (DS1) has a resistance of 5 ohms, then the current in the circuit can be determined. Using this equation and substituting values:

$$I = \frac{E}{R} = \frac{1.5\text{ volts}}{5\text{ ohms}} = .3\text{ ampere}$$

If the flashlight were a two-cell flashlight, we would have twice the voltage, or 3.0 volts, applied to the circuit. Using this voltage in the equation:

$$I = \frac{E}{R} = \frac{3.0\text{ volts}}{5\text{ ohms}} = .6\text{ ampere}$$

You can see that the current has doubled as the voltage has doubled. This demonstrates that the current is directly proportional to the applied voltage.

If the value of resistance of the lamp is doubled, the equation will be:

$$I = \frac{E}{R} = \frac{3.0\text{ volts}}{10\text{ ohms}} = .3\text{ ampere}$$

The current has been reduced to one half of the value of the previous equation, or .3 ampere. This demonstrates that the current is inversely proportional to the resistance. Doubling the value of the resistance of the load reduces circuit current value to one half of its former value.

APPLICATION OF OHM'S LAW

By using Ohm's law, you are able to find the resistance of a circuit, knowing only the voltage and the current in the circuit.

In any equation, if all the variables (parameters) are known except one, that unknown can be found. For example, using Ohm's law, if current (I) and voltage (E) are known, resistance (R) the only parameter not known, can be determined:

1. Basic formula:

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

2. Remove the divisor by multiplying both sides by R:

$$R \times I = \frac{E}{\cancel{R}} \times \frac{\cancel{R}}{1}$$

3. Result of step 2: R x I = E

4. To get R alone (on one side of the equation) divide both sides by I:

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

5. The basic formula, transposed for R, is:

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

Refer to figure 3-3 where E equals 10 volts and I equals 1 ampere. Solve for R, using the equation just explained.

Given: E = 10 volts

I = 1 ampere

Solution:

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

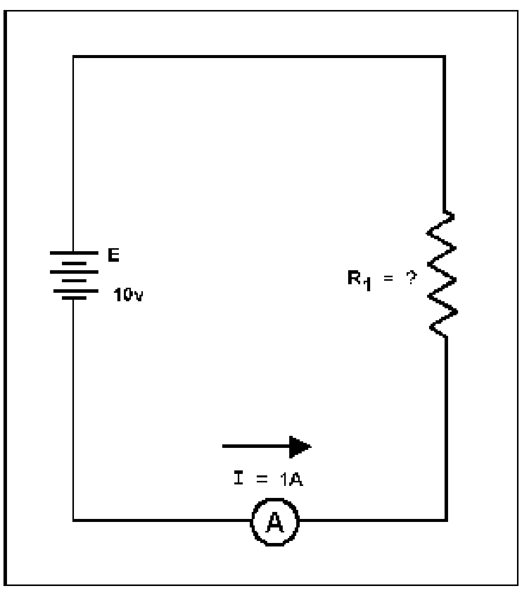


Figure 3-3.—Determining resistance in a basic circuit.

Insert the values of the known quantities:

$$R = \frac{10 \text{ volts}}{1 \text{ ampere}}$$

$$R = 10 \text{ ohms}$$

The basic formula can also be used to solve for E:

Take the basic formula: $I = \frac{E}{R}$

multiply both sides by R:

$$I \times R = \frac{E}{R} \times \frac{R}{1}$$

Results: $E = I \times R$

This equation can be used to find the voltage for the circuit shown in figure 3-4.

Given: $I = .5$ ampere
$R = 45$ ohms

Solution: $E = I \times R$
$E = .5 \text{ ampere} \times 45 \text{ ohms}$
$E = 22.5$ volts

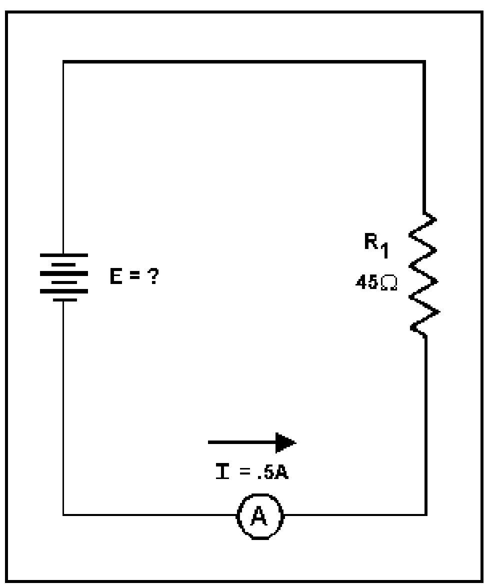


Figure 3-4.—Determining voltage in a basic circuit.

The Ohm's law equation and its various forms may be obtained readily with the aid of figure 3-5. The circle containing E, I, and R is divided into two parts, with E above the line and with I and R below the line. To determine the unknown quantity, first cover that quantity with a finger. The position of the uncovered letters in the circle will indicate the mathematical operation to be performed. For example, to find I, cover I with a finger. The uncovered letters indicate that E is to be divided by R, or

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

To find the formula for E, cover E with your finger. The result indicates that I is to be multiplied by R, or E = IR. To find the formula for R, cover R. The result indicates that E is to be divided by I, or

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

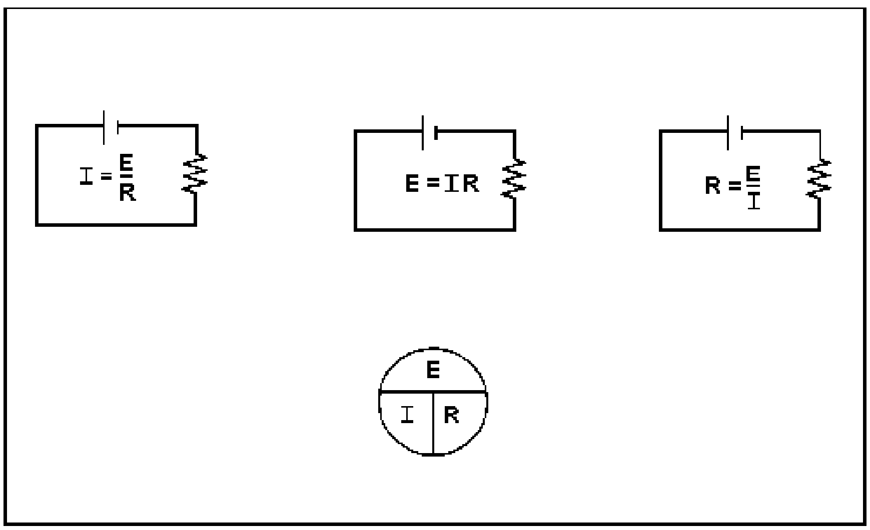


Figure 3-5.—Ohm's law in diagram form.

You are cautioned not to rely wholly on the use of this diagram when you transpose the Ohm's law formulas. The diagram should be used to supplement your knowledge of the algebraic method. Algebra is a basic tool in the solution of electrical problems.

Q4. According to Ohm's law, what happens to circuit current if the applied voltage (a) increases, (b) decreases?

Q5. According to Ohm's law, what happens to circuit current if circuit resistance (a) increases, (b) decreases?

Q6. What is the equation used to find circuit resistance if voltage and current values are known?

GRAPHICAL ANALYSIS OF THE BASIC CIRCUIT

One of the most valuable methods of analyzing a circuit is by constructing a graph. No other method provides a more convenient or more rapid way to observe the characteristics of an electrical device.

The first step in constructing a graph is to obtain a table of data. The information in the table can be obtained by taking measurements on the circuit under examination, or can be obtained theoretically through a series of Ohm's law computations. The latter method is used here.

Since there are three variables (E, I, and R) to be analyzed, there are three distinct graphs that may be constructed.

To construct any graph of electrical quantities, it is standard practice to vary one quantity in a specified way and note the changes which occur in a second quantity. The quantity which is intentionally varied is called the independent variable and is plotted on the horizontal axis. The horizontal axis is known as the X-AXIS. The second quantity, which varies as a result of changes in the first quantity, is called the dependent variable and is plotted on the vertical, or Y-AXIS. Any other quantities involved are held constant.

For example, in the circuit shown in figure 3-6, if the resistance was held at 10 ohms and the voltage was varied, the resulting changes in current could then be graphed. The resistance is the constant, the voltage is the independent variable, and the current is the dependent variable.

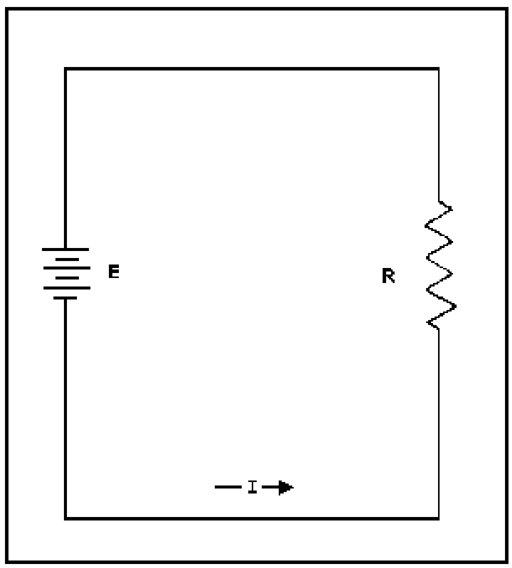
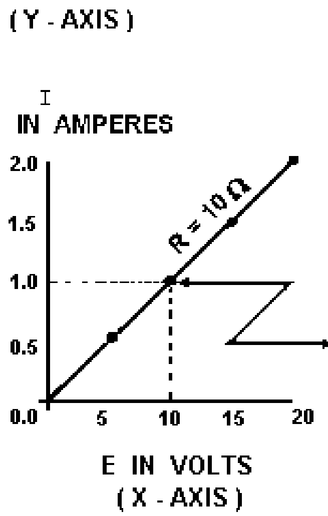


Figure 3-6.—Three variables in a basic circuit.

Figure 3-7 shows the graph and a table of values. This table shows R held constant at 10 ohms as E is varied from 0 to 20 volts in 5-volt steps. Through the use of Ohm's law, you can calculate the value of current for each value of voltage shown in the table. When the table is complete, the information it contains can be used to construct the graph shown in figure 3-7. For example, when the voltage applied to the 10-ohm resistor is 10 volts, the current is 1 ampere. These values of current and voltage determine a point on the graph. When all five points have been plotted, a smooth curve is drawn through the points.



R = 10 Ω	
E	I
0	0.0
5	0.5
10	1.0
15	1.5
20	2.0

Figure 3-7.—Volt-ampere characteristic.

Through the use of this curve, the value of current through the resistor can be quickly determined for any value of voltage between 0 and 20 volts.

Since the curve is a straight line, it shows that equal changes of voltage across the resistor produce equal changes in current through the resistor. This fact illustrates an important characteristic of the basic law—the current varies directly with the applied voltage when the resistance is held constant.

When the voltage across a load is held constant, the current depends solely upon the resistance of the load. For example, figure 3-8 shows a graph with the voltage held constant at 12 volts. The independent variable is the resistance which is varied from 2 ohms to 12 ohms. The current is the dependent variable. Values for current can be calculated as:

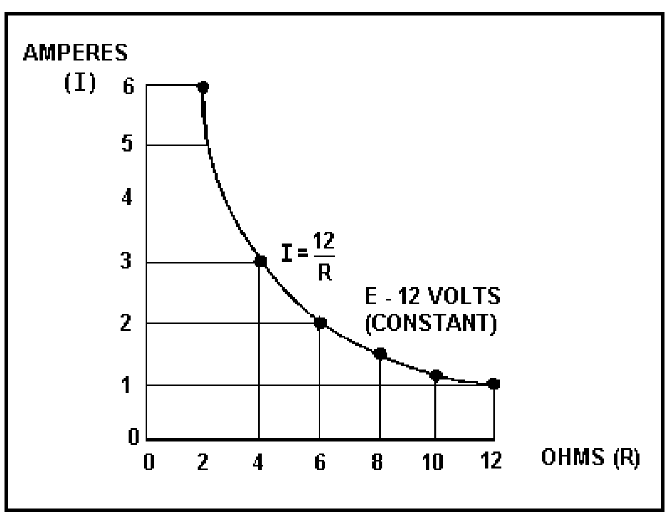


Figure 3-8.—Relationship between current and resistance.

Given: $E = 12 \text{ volts}$

$R = 2 \text{ ohms to } 12 \text{ ohms}$

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

$$I = \frac{12 \text{ volts}}{12 \text{ ohms}} = 1 \text{ ampere}$$

$$I = \frac{12 \text{ volts}}{10 \text{ ohms}} = 1\,2 \text{ ampere}$$

$$I = \frac{12 \text{ volts}}{8 \text{ ohms}} = 1\,5 \text{ ampere}$$

$$I = \frac{12 \text{ volts}}{6 \text{ ohms}} = 2 \text{ ampere}$$

This process can be continued for any value of resistance. You can see that as the resistance is halved, the current is doubled; when the resistance is doubled, the current is halved.

This illustrates another important characteristic of Ohm's law—current varies inversely with resistance when the applied voltage is held constant.

Q7. Using the graph in figure 3-7, what is the approximate value of current when the voltage is 12.5 volts?

Q8. Using the graph in figure 3-8, what is the approximate value of current when the resistance is 3 ohms?

POWER

Power, whether electrical or mechanical, pertains to the rate at which work is being done. Work is done whenever a force causes motion. When a mechanical force is used to lift or move a weight, work is done. However, force exerted WITHOUT causing motion, such as the force of a compressed spring acting between two fixed objects, does not constitute work.

Previously, it was shown that voltage is an electrical force, and that voltage forces current to flow in a closed circuit. However, when voltage exists but current does not flow because the circuit is open, no work is done. This is similar to the spring under tension that produced no motion. When voltage causes electrons to move, work is done. The instantaneous RATE at which this work is done is called the electric power rate, and is measured in WATTS.

A total amount of work may be done in different lengths of time. For example, a given number of electrons may be moved from one point to another in 1 second or in 1 hour, depending on the RATE at which they are moved. In both cases, total work done is the same. However, when the work is done in a short time, the wattage, or INSTANTANEOUS POWER RATE, is greater than when the same amount of work is done over a longer period of time.

As stated, the basic unit of power is the watt. Power in watts is equal to the voltage across a circuit multiplied by current through the circuit. This represents the rate at any given instant at which work is being done. The symbol P indicates electrical power. Thus, the basic power formula is P = E x I, where E is voltage and I is current in the circuit. The amount of power changes when either voltage or current, or both voltage and current, are caused to change.

In practice, the ONLY factors that can be changed are voltage and resistance. In explaining the different forms that formulas may take, current is sometimes presented as a quantity that is changed. Remember, if current is changed, it is because either voltage or resistance has been changed.

Figure 3-9 shows a basic circuit using a source of power that can be varied from 0 to 8 volts and a graph that indicates the relationship between voltage and power.

The resistance of this circuit is 2 ohms; this value does not change. Voltage (E) is increased (by increasing the voltage source), in steps of 1 volt, from 0 volts to 8 volts. By applying Ohm's law, the current (I) is determined for each step of voltage. For instance, when E is 1 volt, the current is:

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

$$I = \frac{1 \text{ volt}}{2 \text{ ohms}}$$

$$I = 0.5 \text{ ampere}$$

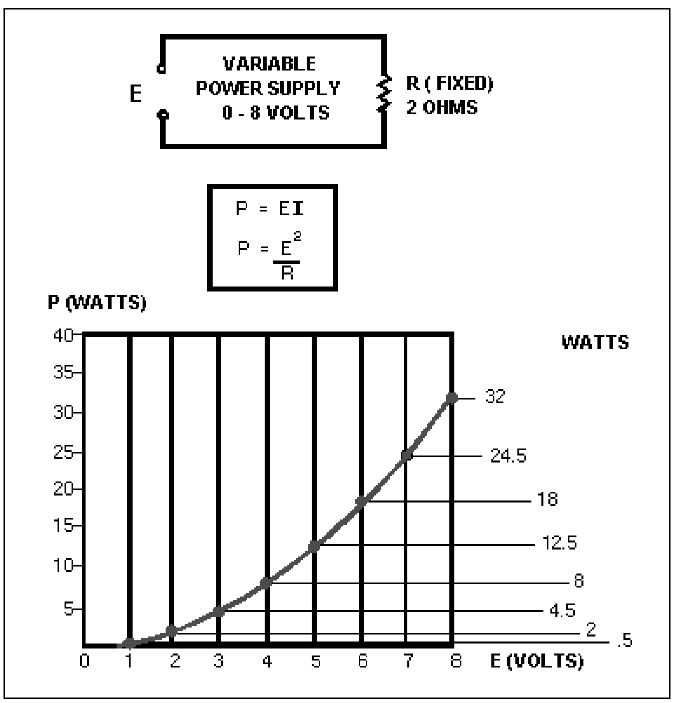


Figure 3-9.—Graph of power related to changing voltage.

Power (P), in watts, is determined by applying the basic power formula:

$$P = E \times I$$
$$P = 1 \text{ volt} \times 0.5 \text{ ampere}$$
$$P = 0.5 \text{ watt}$$

When E is increased to 2 volts:

$$I = \frac{E}{R}$$
$$I = \frac{2 \text{ volts}}{2 \text{ ohms}}$$

$$I = 1 \text{ ampere}$$

and

$$P = E \text{ x } I$$

$$P = 2 \text{ volts x } 1 \text{ ampere}$$

$$P = 2 \text{ watts}$$

When E is increased to 3 volts:

$$I = \frac{E}{R}$$
$$I = \frac{3 \text{ volts}}{2 \text{ ohms}}$$

$$I = 1.5 \text{ amperes}$$

and

$$P = E \times I$$
$$P = 3 \text{ volts} \times 1.5 \text{ ampere}$$
$$P = 4.5 \text{ watts}$$

You should notice that when the voltage was increased to 2 volts, the power increased from .5 watts to 2 watts or 4 times. When the voltage increased to 3 volts, the power increased to 4.5 watts or 9 times. This shows that if the resistance in a circuit is held constant, the power varies directly with the SQUARE OF THE VOLTAGE.

Another way of proving that power varies as the square of the voltage when resistance is held constant is:

Since: $I = \dfrac{E}{R}$

By substitution in: $P = E \times I$

You get: $P = E \times \dfrac{E}{R}$

Or: $P = \dfrac{E \times E}{R}$

Therefore: $P = \dfrac{E^2}{R}$

Another important relationship may be seen by studying figure 3-10. Thus far, power has been calculated with voltage and current (P = E x I), and with voltage and resistance

$$P = \frac{E^2}{R}$$

Referring to figure 3-10, note that power also varies as the square of current just as it does with voltage. Thus, another formula for power, with current and resistance as its factors, is $P = I^2R$. This can be proved by:

Since: $E = I \times R$

By substituition in: $P = E \times I$

You get: $P = I \times R \times I$

Or: $P = I \times I \times R$

Therefore: $P = I^2 \times R$

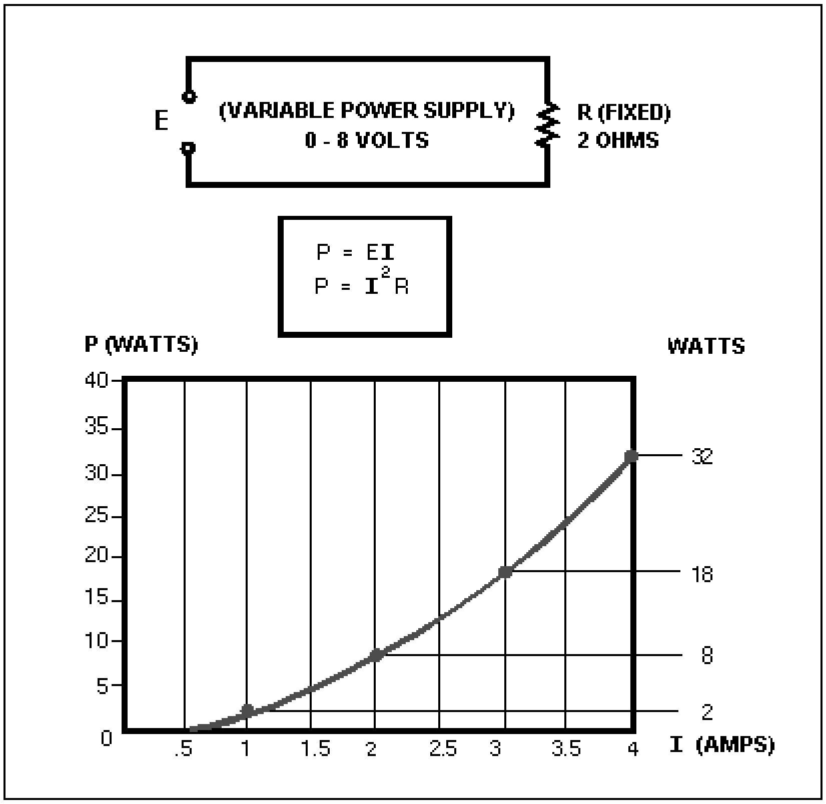


Figure 3-10.—Graph of power related to changing current.

Up to this point, four of the most important electrical quantities have been discussed. These are voltage (E), current (I), resistance (R), and power (P). You must understand the relationships which exist among these quantities because they are used throughout your study of electricity. In the preceding paragraphs, P was expressed in terms of alternate pairs of the other three basic quantities E, I, and R. In practice, you should be able to express any one of these quantities in terms of any two of the others.

Figure 3-11 is a summary of 12 basic formulas you should know. The four quantities E, I, R, and P are at the center of the figure. Adjacent to each quantity are three segments. Note that in each segment, the basic quantity is expressed in terms of two other basic quantities, and no two segments are alike.

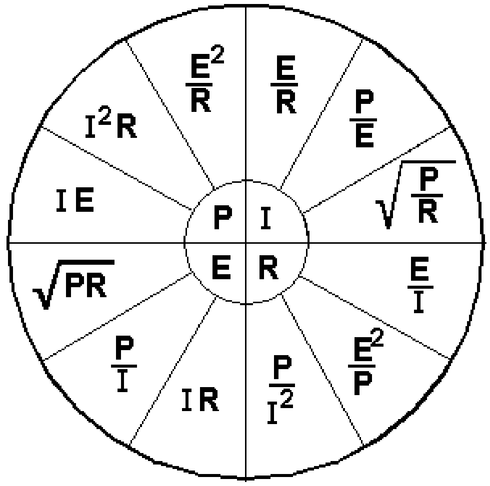


Figure 3-11.—Summary of basic formulas.

For example, the formula wheel in figure 3-11 could be used to find the formula to solve the following problem:

A circuit has a voltage source that delivers 6 volts and the circuit uses 3 watts of power. What is the resistance of the load?

Since R is the quantity you have been asked to find, look in the section of the wheel that has R in the center. The segment

$$\frac{E^2}{P}$$

contains the quantities you have been given. The formula you would use is

$$R = \frac{E^2}{P}$$

The problem can now be solved.

Given: $E = 6 \text{ volts}$

$P = 3 \text{ watts}$

Soultion: $R = \frac{E^2}{P}$

$$\frac{(6 \text{ volts})^2}{3 \text{ watts}}$$

$$R = \frac{36}{3} = 12 \text{ ohms}$$

Q9. What is the term applied to the rate at which a mechanical or electrical force causes motion?

Q10. How can the amount of current be changed in a circuit?

Q11. What are the three formulas for electrical power?

POWER RATING

Electrical components are often given a power rating. The power rating, in watts, indicates the rate at which the device converts electrical energy into another form of energy, such as light, heat, or motion. An example of such a rating is noted when comparing a 150-watt lamp to a 100-watt lamp. The higher wattage rating of the 150-watt lamp indicates it is capable of converting more electrical energy into light energy than the lamp of the lower rating. Other common examples of devices with power ratings are soldering irons and small electric motors.

In some electrical devices the wattage rating indicates the maximum power the device is designed to use rather than the normal operating power. A 150-watt lamp, for example, uses 150 watts <u>when operated at the specified voltage printed on the bulb</u>. In contrast, a device such as a resistor is not normally given a voltage or a current rating. A resistor is given a power rating in watts and can be operated at <u>any combination of voltage and current</u> as long as the power rating is not exceeded. In most circuits, the actual power used by a resistor is considerably less than the power rating of the resistor because a 50% safety factor is used. For example, if a resistor normally used 2 watts of power, a resistor with a power rating of 3 watts would be used.

Resistors of the same resistance value are available in different wattage values. Carbon resistors, for example, are commonly made in wattage ratings of 1/8, 1/4, 1/2, 1, and 2 watts. The larger the physical size of a carbon resistor the higher the wattage rating. This is true because a larger surface area of material radiates a greater amount of heat more easily.

When resistors with wattage ratings greater than 5 watts are needed, wirewound resistors are used. Wirewound resistors are made in values between 5 and 200 watts. Special types of wirewound resistors are used for power in excess of 200 watts.

As with other electrical quantities, prefixes may be attached to the word watt when expressing very large or very small amounts of power. Some of the more common of these are the kilowatt (1,000 watts), the megawatt (1,000,000 watts), and the milliwatt (1/1,000 of a watt).

Q12. What is the current in a circuit with 5 ohms of resistance that uses 180 watts of power? (refer to figure 3-12)

Q13. What type of resistor should be used in the circuit described in question 12?

Q14. What is the power used in a circuit that has 10 amperes of current through a 10-ohm resistor?

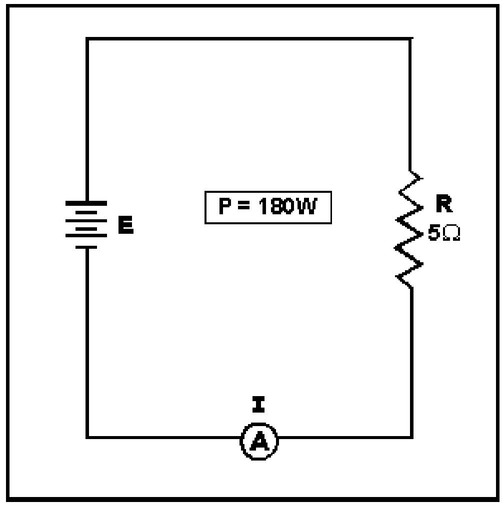


Figure 3-12.—Circuit for computing electrical quantities.

POWER CONVERSION AND EFFICIENCY

The term power consumption is common in the electrical field. It is applied to the use of power in the same sense that gasoline consumption is applied to the use of fuel in an automobile.

Another common term is power conversion. Power is used by electrical devices and is converted from one form of energy to another. An electrical motor converts electrical energy to mechanical energy. An electric light bulb converts electrical energy into light energy and an electric range converts electrical energy into heat energy. Power used by electrical devices is measured in energy. This practical unit of electrical energy is equal to 1 watt of power used continuously for 1 hour. The term kilowatt hour (kWh) is used more extensively on a daily basis and is equal to 1,000 watt-hours.

The EFFICIENCY of an electrical device is the ratio of power converted to useful energy divided by the power consumed by the device. This number will always be less than one (1.00) because of the losses in any electrical device. If a device has an efficiency rating of .95, it effectively transforms 95 watts into useful energy for every 100 watts of input power. The other 5 watts are lost to heat, or other losses which cannot be used.

Calculating the amount of power converted by an electrical device is a simple matter. You need to know the length of time the device is operated and the input power or horsepower rating. Horsepower, a unit of work, is often found as a rating on electrical motors. One horsepower is equal to 746 watts. Example: A 3/4-hp motor operates 8 hours a day. How much power is converted by the motor per month? How many kWh does this represent?

Given: $t = 8$ hrs x 30 days

$P = 3/4$ hp

Solution: Convert horsepower to watts

$P = \text{hp} \times 746$ watts

$P = 3/4 \times 746$ watts

P = 559 watts

Convert watts to watt-hours

P = work x time

P = 559 watts x 8 x 30

P = 134,000 watt-hours per month

(NOTE: These figures are rounded to the nearest 1000.)

To convert to kWh

$$P = \frac{\text{Power in watt-hours}}{1000}$$

$$P = \frac{134{,}000 \text{ in watt-hours}}{1000}$$

$$P = 134 \text{ kWh}$$

If the motor actually uses 137 kWh per month, what is the efficiency of the motor?

Given: Power converted = 134 kWh per month

Power used = 137 kWh per month

Solution:

$$EFF = \frac{\text{Power converted}}{\text{Power used}}$$

$$EFF = \frac{134 \text{ kWh per month}}{137 \text{ kWh per month}}$$

$$EFF = .978 \text{ (Rounded to three figures)}$$

Q15. How much power is converted by a 1-horsepower motor in 12 hours?

Q16. What is the efficiency of the motor if it actually uses 9.5 kWh in 12 hours?

SERIES DC CIRCUITS

When two unequal charges are connected by a conductor, a complete pathway for current exists. An electric circuit is a complete conducting pathway. It consists not only of the conductor, but also includes the path through the voltage source. Inside the voltage source current flows from the positive terminal, through the source, emerging at the negative terminal.

SERIES CIRCUIT CHARACTERISTICS

A SERIES CIRCUIT is defined as a circuit that contains only ONE PATH for current flow. To compare the basic circuit that has been discussed and a more complex series circuit, figure 3-13 shows two circuits. The basic circuit has only one lamp and the series circuit has three lamps connected in series.

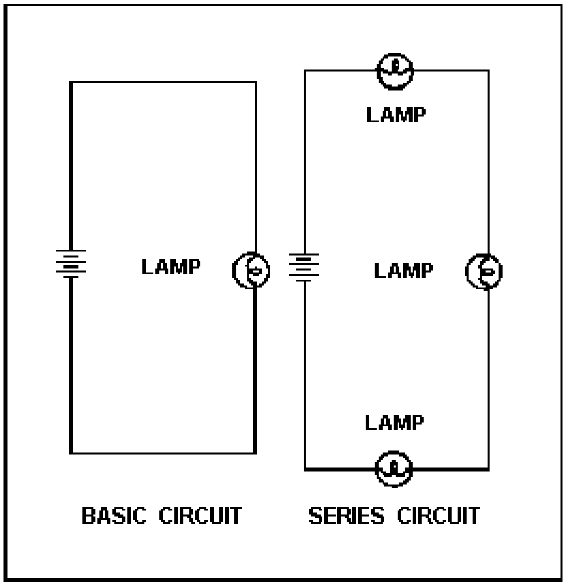


Figure 3-13.—Comparison of basic and series circuits.

Resistance in a Series Circuit

Referring to figure 3-13, the current in a series circuit must flow through each lamp to complete the electrical path in the circuit. Each additional lamp offers added resistance. In a series circuit, THE TOTAL CIRCUIT RESISTANCE (R_T) IS EQUAL TO THE SUM OF THE INDIVIDUAL RESISTANCES.

As an equation: $R_T = R_1 + R_2 + R_3 + \ldots R_n$

NOTE: The subscript n denotes any number of additional resistances that might be in the equation.

Example: In figure 3-14 a series circuit consisting of three resistors: one of 10 ohms, one of 15 ohms, and one of 30 ohms, is shown. A voltage source provides 110 volts. What is the total resistance?

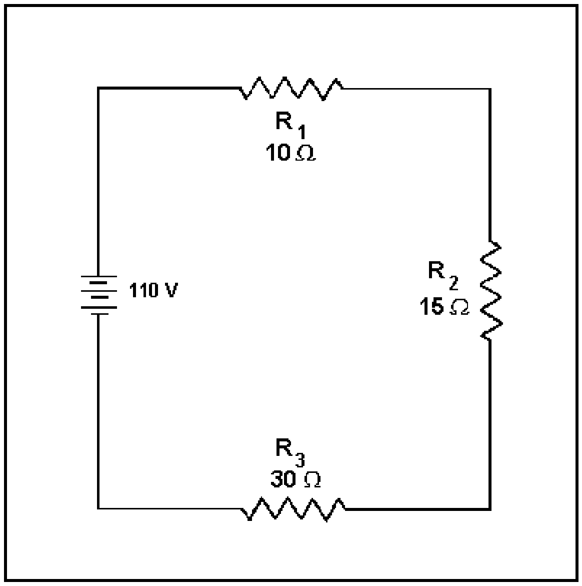


Figure 3-14.—Solving for total resistance in a series circuit.

Given: $R_1 = 10$ ohms
$R_2 = 15$ ohms
$R_3 = 30$ ohms

Soulution: $R_T = R_1 + R_2 + R_3$
$R_T = 10$ ohms $+ 15$ ohms
$+ 30$ ohms
$R_T = 55$ ohms

In some circuit applications, the total resistance is known and the value of one of the circuit resistors has to be determined. The equation $R_T = R_1 + R_2 + R_3$ can be transposed to solve for the value of the unknown resistance.

Example: In figure 3-15 the total resistance of a circuit containing three resistors is 40 ohms. Two of the circuit resistors are 10 ohms each. Calculate the value of the third resistor (R_3).

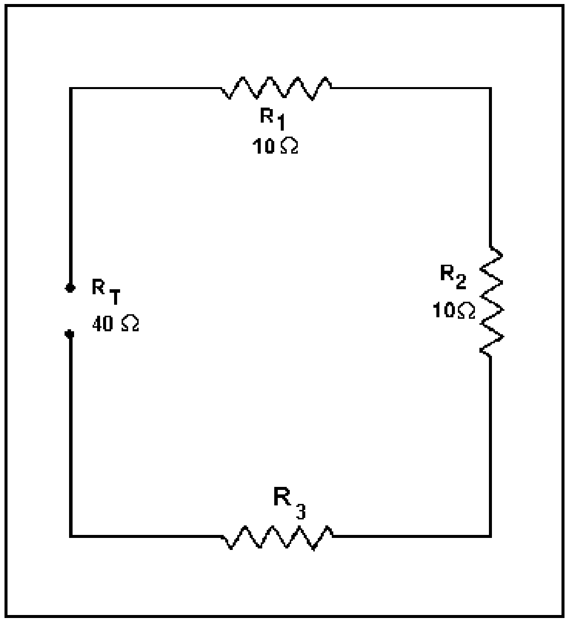


Figure 3-15.—Calculating the value of one resistance in a series circuit.

Given:

R_1 = 40 ohms
R_2 = 10 ohms
R_3 = 10 ohms

Solution:

$$R_T = R_1 + R_2 + R_3$$

(Subtract $R_1 + R_2$ from both sides of the equation.)

$$R_T - R_1 - R_2 = R_3$$
$$R_3 = R_T - R_1 - R_2$$
$$R_3 = 40 \text{ ohms} - 10 \text{ ohms} - 10 \text{ ohms}$$
$$R_3 = 40 \text{ ohms} - 20 \text{ ohms}$$
$$R_3 = 20 \text{ ohms}$$

Current in a Series Circuit

Since there is only one path for current in a series circuit, the same current must flow through each component of the circuit. To determine the current in a series circuit, only the current through one of the components need be known.

The fact that the same current flows through each component of a series circuit can be verified by inserting meters into the circuit at various points, as shown in figure 3-16. If this were done, each meter would be found to indicate the same value of current.

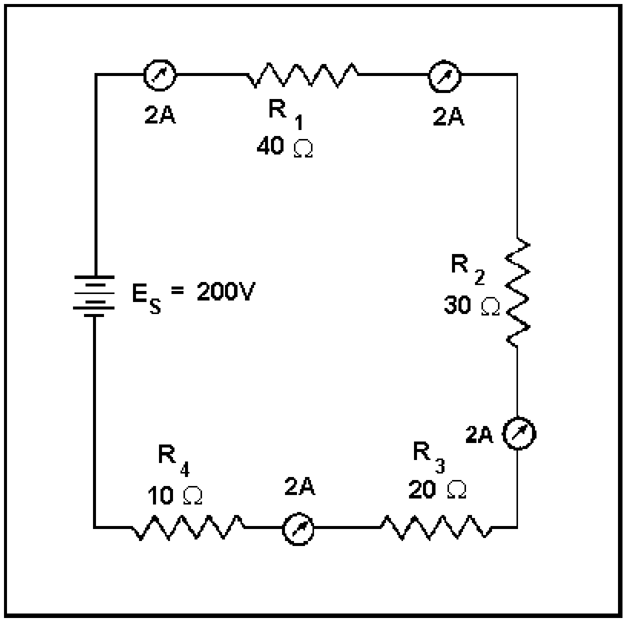


Figure 3-16.—Current in a series circuit.

Voltage in a Series Circuit

The voltage dropped across the resistor in a circuit consisting of a single resistor and a voltage source is the total voltage across the circuit and is equal to the applied voltage. The total voltage across a series circuit that consists of more than one resistor is also equal to the applied voltage, but consists of the sum of the individual resistor voltage drops. In any series circuit, the SUM of the resistor voltage drops must equal the source voltage. This statement can be proven by an examination of the circuit shown in figure 3-17. In this circuit a source potential (E_T) of 20 volts is dropped across a series circuit consisting of two 5-ohm resistors. The total resistance of the circuit (R_T) is equal to the sum of the two individual resistances, or 10 ohms. Using Ohm's law the circuit current may be calculated as follows:

Given: $E_T = 20$ volts
$R_T = 10$ ohms

Solution: $$I_T = \frac{E_T}{R_T}$$

$$I_T = \frac{20 \text{ volts}}{10 \text{ ohms}}$$

$$I_T = 2 \text{ amps}$$

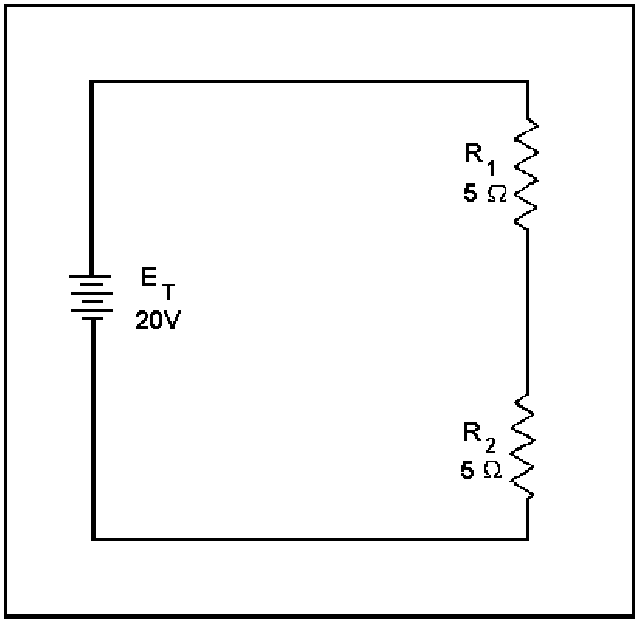


Figure 3-17.—Calculating individual voltage drops in a series circuit.

Since the value of the resistors is known to be 5 ohms each, and the current through the resistors is known to be 2 amperes, the voltage drops across the resistors can be calculated. The voltage (E_1) across R_1 is therefore:

Given: $I_1 = 2$ amperes
$R_1 = 5$ ohms

Solution: $E_1 = I_1 \times R_1$
$E_1 = 2 \text{ amperes} \times 5 \text{ ohms}$
$E_1 = 10 \text{ volts}$

By inspecting the circuit, you can see that R_2 is the same ohmic value as R_1 and carries the same current. The voltage drop across R_2 is therefore also equal to 10 volts. Adding these two 10-volts drops together gives a total drop of 20 volts, exactly equal to the applied voltage. For a series circuit then:

$$E_T = E_1 = E_2 + E_3 = . . . E_n$$

Example: A series circuit consists of three resistors having values of 20 ohms, 30 ohms, and 50 ohms, respectively. Find the applied voltage if the current through the 30 ohm resistor is 2 amps. (The abbreviation amp is commonly used for ampere.)

To solve the problem, a circuit diagram is first drawn and labeled (fig 3-18).

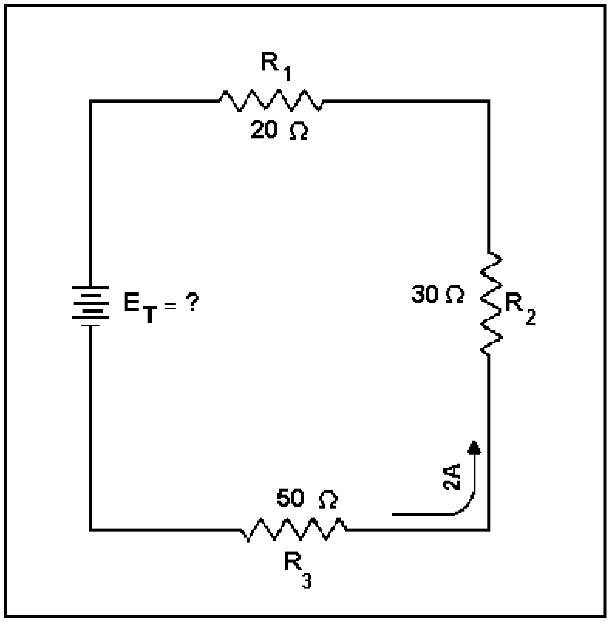


Figure 3-18.—Solving for applied voltage in a series circuit.

Given:

$R_1 = 20$ ohms
$R_2 = 30$ ohms
$R_3 = 50$ ohms
$I = 2$ amps

Solution:

$E_T = E_1 + E_2 + E_3$
$E_1 = R_1 \times I_1$ (I_1= The current through resistor R_1)
$E_2 = R_2 \times I_2$
$E_3 = R_3 \times I_3$

Substituting:

$$E_T = (R_1 \times I_1) + (R_2 \times I_2) + (R_3 \times I_3)$$

$$E_T = (20 \text{ ohms} \times 2 \text{ amps}) + (30 \text{ ohms} \times 2 \text{ amps}) + (50 \text{ ohms} \times 2 \text{ amps})$$

$$E_T = 40 \text{ volts} + 60 \text{ volts} + 100 \text{ volts}$$

$$E_T = 200 \text{ volts}$$

NOTE: When you use Ohm's law, the quantities for the equation MUST be taken from the SAME part of the circuit. In the above example the voltage across R_2 was computed using the current through R_2 and the resistance of R_2.

The value of the voltage dropped by a resistor is determined by the applied voltage and is in proportion to the circuit resistances. The voltage drops that occur in a series circuit are in direct proportion to the resistances. This is the result of having the same current flow through each resistor—the larger the ohmic value of the resistor, the larger the voltage drop across it.

Q17. A series circuit consisting of three resistors has a current of 3 amps. If R_1 = 20 ohms, R_2= 60 ohms, and R_3 = 80 ohms, what is the (a) total resistance and (b) source voltage of the circuit?

Q18. What is the voltage dropped by each resistor of the circuit described in question 17?

Q19. If the current was increased to 4 amps, what would be the voltage drop across each resistor in the circuit described in question 17?

Q20. What would have to be done to the circuit described in question 17 to increase the current to 4 amps?

Power in a Series Circuit

Each of the resistors in a series circuit consumes power which is dissipated in the form of heat. Since this power must come from the source, the total power must be equal to the power consumed by the circuit resistances. In a series circuit the total power is equal to the SUM of the power dissipated by the individual resistors. Total power (P_T) is equal to:

$$P_T = P_1 + P_2 + P_3 \ldots P_n$$

Example: A series circuit consists of three resistors having values of 5 ohms, 10 ohms, and 15 ohms. Find the total power when 120 volts is applied to the circuit. (See fig. 3-19.)

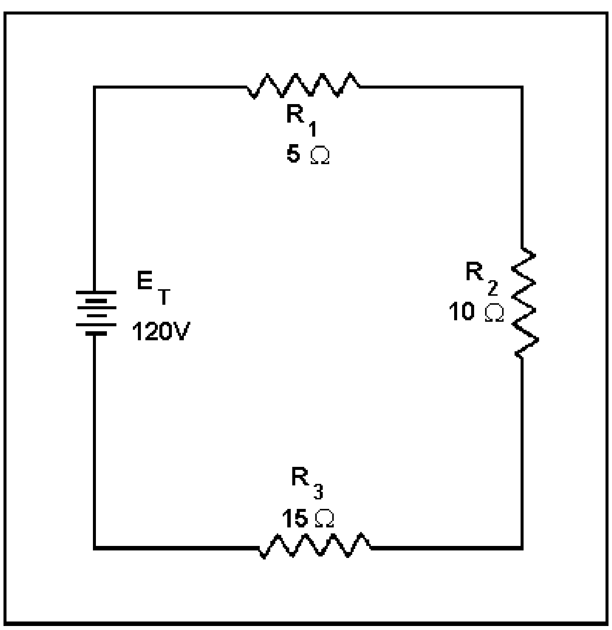


Figure 3-19.—Solving for total power in a series circuit.

Given:

$$R_1 = 5 \text{ ohms}$$
$$R_2 = 10 \text{ ohms}$$
$$R_3 = 15 \text{ ohms}$$
$$E = 120 \text{ volts}$$

Solution: The total resistance is found first.

$$R_T = R_1 + R_2 + R_3$$
$$R_T = 5 \text{ ohms} + 10 \text{ ohms} + 15 \text{ ohms}$$
$$R_T = 30 \text{ ohms}$$

By using the total resistance and the applied voltage, the circuit current is calculated.

$$I = \frac{E_T}{R_T}$$

$$I = \frac{120 \text{ volts}}{30 \text{ ohms}}$$

$$I = 4 \text{ amps}$$

By means of the power formulas, the power can be calculated for each resistor:

For R_1:
$$P_1 = I^2 \times R_1$$
$$P_1 = (4 \text{ amps})^2 \times 5 \text{ ohms}$$
$$P_1 = 80 \text{ watts}$$

For R_2:
$$P_2 = I^2 \times R_2$$
$$P_2 = (4 \text{ amps})^2 \times 10 \text{ ohms}$$
$$P_2 = 160 \text{ watts}$$

For R_3:
$$P_3 = I^2 \times R_3$$
$$P_3 = (4 \text{ amps})^2 \times 15 \text{ ohms}$$
$$P_3 = 240 \text{ watts}$$

For total power:
$$P_T = P_1 + P_2 + P_3$$
$$P_T = 80 \text{ watts} + 160 \text{ watts} + 240 \text{ watts}$$
$$P_T = 480 \text{ watts}$$

To check the answer, the total power delivered by the source can be calculated:

$$P_{source} = I_{source} \times E_{source}$$
$$P_{source} = 4\ amps \times 120\ volts$$
$$P_{source} = 480\ watts$$

The total power is equal to the sum of the power used by the individual resistors.

SUMMARY OF CHARACTERISTICS

The important factors governing the operation of a series circuit are listed below. These factors have been set up as a group of rules so that they may be easily studied. These rules must be completely understood before the study of more advanced circuit theory is undertaken.

Rules for Series DC Circuits

1. The same current flows through each part of a series circuit.
2. The total resistance of a series circuit is equal to the sum of the individual resistances.
3. The total voltage across a series circuit is equal to the sum of the individual voltage drops.
4. The voltage drop across a resistor in a series circuit is proportional to the ohmic value of the resistor.
5. The total power in a series circuit is equal to the sum of the individual powers used by each circuit component.

SERIES CIRCUIT ANALYSIS

To establish a procedure for solving series circuits, the following sample problems will be solved.

Example: Three resistors of 5 ohms, 10 ohms, and 15 ohms are connected in series with a power source of 90 volts as shown in figure 3-20. Find the total resistance, circuit current, voltage drop of each resistor, power of each resistor, and total power of the circuit.

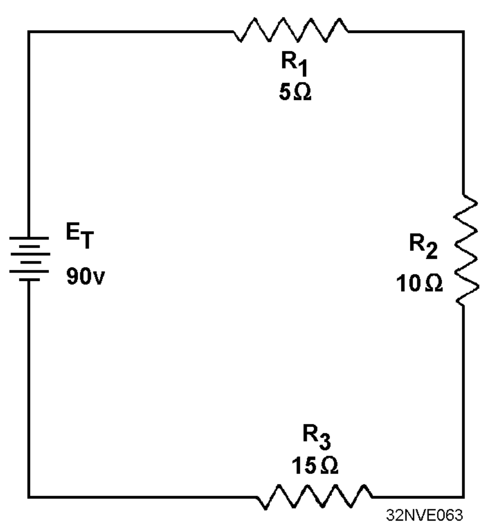


Figure 3-20.—Solving for various values in a series circuit.

In solving the circuit the total resistance will be found first. Next, the circuit current will be calculated. Once the current is known, the voltage drops and power dissipations can be calculated.

Given:

$R_1 = 5$ ohms
$R_2 = 10$ ohms
$R_3 = 15$ ohms
$E = 90$ volts

Solution:

$R_T = R_1 + R_2 + R_3$
$R_T = 5 \text{ ohms} + 10 \text{ ohms} + 15 \text{ ohms}$
$R_T = 30$ ohms

$$I = \frac{E_T}{R_T}$$

$$I = \frac{90 \text{ volts}}{30 \text{ ohms}}$$

$I = 3$ amps

$E_1 = IR_1$
$E_1 = 3 \text{ amperes} \times 5 \text{ ohms}$
$E_1 = 15$ volts

$E_2 = IR_2$
$E_2 = 3 \text{ amperes} \times 10 \text{ ohms}$
$E_2 = 30$ volts

$E_3 = IR_3$
$E_3 = 3 \text{ amperes} \times 15 \text{ ohms}$
$E_3 = 45$ volts

$P_1 = I \times E_1$
$P_1 = 3 \text{ amperes} \times 15 \text{ volts}$
$P_1 = 45$ watts

$P_2 = I \times E_2$
$P_2 = 3 \text{ amperes} \times 30 \text{ volts}$
$P_2 = 90$ watts

$$P_3 = I \times E_3$$
$$P_3 = 3 \text{ amperes} \times 45 \text{ volts}$$
$$P_3 = 135 \text{ watts}$$

$$P_T = E_1 \times I$$
$$P_T = 90 \text{ volts} \times 3 \text{ amps}$$
$$P_T = 270 \text{ watts}$$

or

$$P_T = P_1 + P_2 + P_3$$
$$P_T = 45 \text{ watts} + 90 \text{ watts} + 135 \text{ watts}$$
$$P_T = 270 \text{ watts}$$

Example: Four resistors, R_1 = 10 ohms, R_2 = 10 ohms, R_3 = 50 ohms, and R_4 = 30 ohms, are connected in series with a power source as shown in figure 3-21. The current through the circuit is 1/2 ampere.

a. What is the battery voltage?

b. What is the voltage across each resistor?

c. What is the power expended in each resistor?

d. What is the total power?

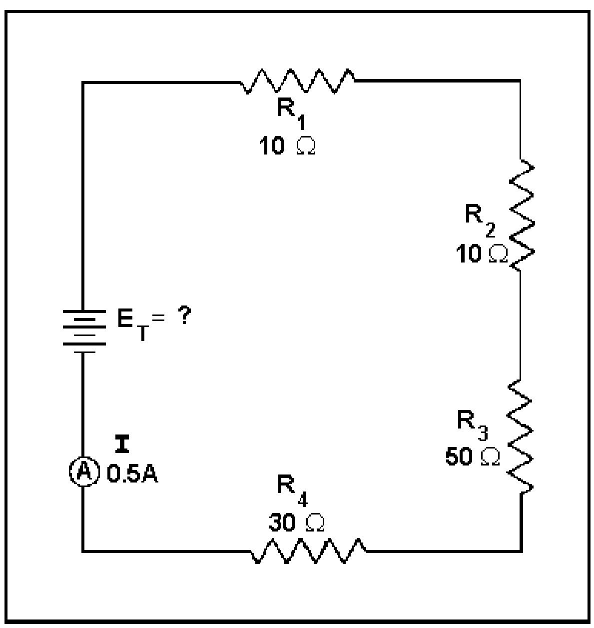


Figure 3-21.—Computing series circuit values.

Given:

$$R_1 = 10 \text{ ohms}$$
$$R_2 = 10 \text{ ohms}$$
$$R_3 = 50 \text{ ohms}$$
$$R_4 = 30 \text{ ohms}$$
$$I = 0.5 \text{ amps}$$

Solution (a):

$$E_T = IR_T$$
$$R_T = R_1 + R_2 + R_3 + R_4$$
$$R_T = 10 \text{ ohms} + 10 \text{ ohms} + 50 \text{ ohms} + 30 \text{ ohms}$$
$$R_T = 100 \text{ ohms}$$
$$E_T = 0.5 \text{ amps} \times 100 \text{ ohms}$$
$$E_T = 50 \text{ volts}$$

Solution (b):

$$E_1 = IR_1$$
$$E_1 = 0.5 \text{ amperes} \times 10 \text{ ohms}$$
$$E_1 = 5 \text{ volts}$$

$$E_2 = IR_2$$
$$E_2 = 0.5 \text{ amperes} \times 10 \text{ ohms}$$
$$E_2 = 5 \text{ volts}$$

$$E_3 = IR_3$$
$$E_3 = 0.5 \text{ amperes} \times 50 \text{ ohms}$$
$$E_3 = 25 \text{ volts}$$

$$E_4 = IR_4$$
$$E_4 = 0.5 \text{ amperes} \times 30 \text{ ohms}$$
$$E_4 = 15 \text{ volts}$$

Solution (c):

$$P_1 = IE_1$$
$$P_1 = 0.5 \text{ amperes} \times 5 \text{ volts}$$
$$P_1 = 2.5 \text{ watts}$$

$$P_2 = IE_2$$
$$P_2 = 0.5 \text{ amperes} \times 5 \text{ volts}$$
$$P_2 = 2.5 \text{ watts}$$

$$P_3 = IE_3$$
$$P_3 = 0.5 \text{ amperes} \times 25 \text{ volts}$$
$$P_3 = 12.5 \text{ watts}$$

$$P_4 = IE_4$$
$$P_4 = 0.5 \text{ amperes} \times 15 \text{ volts}$$
$$P_4 = 7.5 \text{ watts}$$

Solution (d):

$$P_T = P_1 + P_2 + P_3 + P_4$$
$$P_T = 2.5 \text{ watts} + 2.5 \text{ watts} + 12.5 \text{ watts} + 7.5 \text{ watts}$$
$$P_T = 25 \text{ watts}$$

or

$$P_T = IE_T$$
$$P_T = 0.5 \text{ amperes} \times 50 \text{ volts}$$
$$P_T = 25 \text{ watts}$$

or

$$P_T = \frac{{E_T}^2}{R_T}$$

$$P_T = \frac{(50 \text{ volts})^2}{100 \text{ ohms}}$$

$$P_T = \frac{2500 \text{ volts}}{100 \text{ ohms}}$$

$$P_T = 25 \text{ watts}$$

An important fact to keep in mind when applying Ohm's law to a series circuit is to consider whether the values used are component values or total values. When the information available enables the use of Ohm's law to find total resistance, total voltage, and total current, total values must be inserted into the formula. To find total resistance:

$$R_T = \frac{E_T}{I_T}$$

To find total voltage:

$$E_T = I_T = R_T$$

To find total current:

$$I_T = \frac{E_T}{R_T}$$

NOTE: I_T is equal to I in a series circuit. However, the distinction between I_T and I in the formula should be noted. The reason for this is that future circuits may have several currents, and it will be necessary to differentiate between I_T and other currents.

To compute any quantity (E, I, R, or P) associated with a single given resistor, the values used in the formula must be obtained from that particular resistor. For example, to find the value of an unknown resistance, the voltage across and the current through that particular resistor must be used.

To find the value of a resistor:

$$R = \frac{E_R}{I_R}$$

To find the voltage drop across a resistor:

$$E_R = I_R \times R$$

To find current through a resistor:

$$I_R = \frac{E_R}{R}$$

Q21. A series circuit consists of two resistors in series. R_1 = 25 ohms and R_2 = 30 ohms. The circuit current is 6 amps. What is the (a) source voltage, (b) voltage dropped by each resistor, (c) total power, and (d) power used by each resistor?

KIRCHHOFF'S VOLTAGE LAW

In 1847, G. R. Kirchhoff extended the use of Ohm's law by developing a simple concept concerning the voltages contained in a series circuit loop. Kirchhoff's voltage law states:

"The algebraic sum of the voltage drops in any closed path in a circuit and the electromotive forces in that path is equal to zero."

To state Kirchhoff's law another way, the voltage drops and voltage sources in a circuit are equal at any given moment in time. If the voltage sources are assumed to have one sign (positive or negative) at that instant and the voltage drops are assumed to have the opposite sign, the result of adding the voltage sources and voltage drops will be zero.

NOTE: The terms electromotive force and emf are used when explaining Kirchhoff's law because Kirchhoff's law is used in alternating current circuits (covered in Module 2). In applying Kirchhoff's law to direct current circuits, the terms electromotive force and emf apply to voltage sources such as batteries or power supplies.

Through the use of Kirchhoff's law, circuit problems can be solved which would be difficult, and often impossible, with knowledge of Ohm's law alone. When Kirchhoff's law is properly applied, an equation can be set up for a closed loop and the unknown circuit values can be calculated.

POLARITY OF VOLTAGE

To apply Kirchhoff's voltage law, the meaning of voltage polarity must be understood.

In the circuit shown in figure 3-22, the current is shown flowing in a counterclockwise direction. Notice that the end of resistor R_1, into which the current flows, is marked NEGATIVE (−). The end of R_1 at which the current leaves is marked POSITIVE (+). These polarity markings are used to show that the end of R_1 into which the current flows is at a higher negative potential than the end of the resistor at which the current leaves. Point A is more negative than point B.

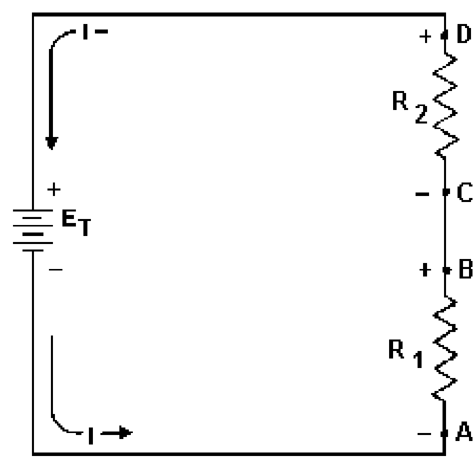


Figure 3-22.—Voltage polarities.

Point C, which is at the same potential as point B, is labeled negative. This is to indicate that point C is more negative than point D. To say a point is positive (or negative) without stating what the polarity is based upon has no meaning. In working with Kirchhoff's law, positive and negative polarities are assigned in the direction of current flow.

APPLICATION OF KIRCHHOFF'S VOLTAGE LAW

Kirchhoff's voltage law can be written as an equation, as shown below:

$$E_a + E_b + E_c + \dots E_n = 0$$

where E_a, E_b, etc., are the voltage drops or emf's around any closed circuit loop. To set up the equation for an actual circuit, the following procedure is used.

1. Assume a direction of current through the circuit. (The correct direction is desirable but not necessary.)

2. Using the assumed direction of current, assign polarities to all resistors through which the current flows.

3. Place the correct polarities on any sources included in the circuit.

4. Starting at any point in the circuit, trace around the circuit, writing down the amount and polarity of the voltage across each component in succession. The polarity used is the sign AFTER the assumed current has passed through the component. Stop when the point at which the trace was started is reached.

5. Place these voltages, with their polarities, into the equation and solve for the desired quantity.

Example: Three resistors are connected across a 50-volt source. What is the voltage across the third resistor if the voltage drops across the first two resistors are 25 volts and 15 volts?

Solution: First, a diagram, such as the one shown in figure 3-23, is drawn. Next, a direction of current is assumed (as shown). Using this current, the polarity markings are placed at each end of each resistor and also on the terminals of the source. Starting at point A, trace around the circuit in the direction of current flow, recording the voltage and polarity of each component. Starting at point A and using the components from the circuit:

$$(+E_x) + (+E_2) + (+E_1) + (-E_A) = 0$$

Substituting values from the circuit:

$$E_x + 15 \text{ volts} + 25 \text{ volts} - 50 \text{ volts} = 0$$
$$E_x - 10 \text{ volts} = 0$$
$$E_x = 10 \text{ volts}$$

The unknown voltage (E_x) is found to be 10 volts

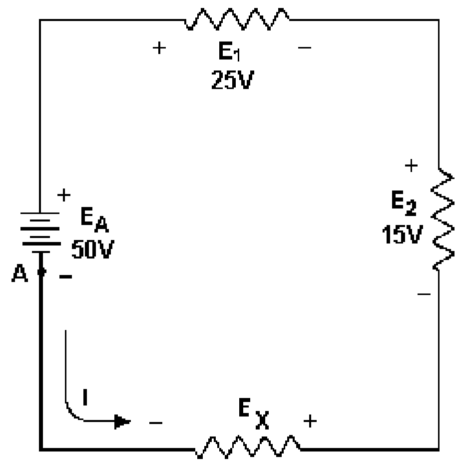


Figure 3-23.—Determining unknown voltage in a series circuit.

Using the same idea as above, you can solve a problem in which the current is the unknown quantity.

Example: A circuit having a source voltage of 60 volts contains three resistors of 5 ohms, 10 ohms, and 15 ohms. Find the circuit current.

Solution: Draw and label the circuit (fig. 3-24). Establish a direction of current flow and assign polarities. Next, starting at any point—point A will be used in this example—write out the loop equation.

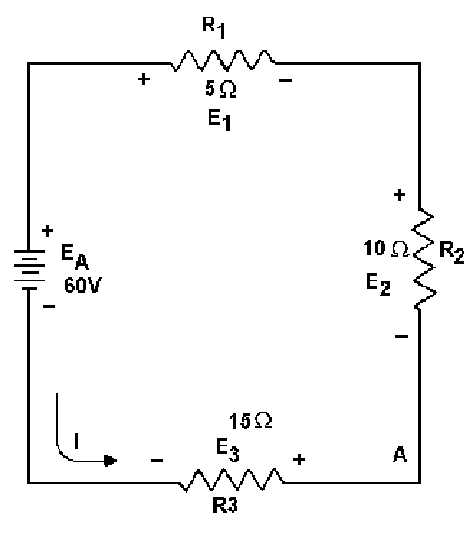


Figure 3-24.—Correct direction of assumed current.

Basic equation:

$$E_2 + E_1 + E_A + E_3 = 0$$

Since E=IR, by substitution:

$$(I \times R_2) + (I \times R_1) + E_A + (I \times R_3) = 0$$

Substituting Values:

$$(I \times 10 \text{ ohms}) + (I \times 5 \text{ ohms}) + (-60 \text{ volts}) + (I \times 15 \text{ ohms}) = 0$$

Combining like terms:

$$(I \times 30 \text{ ohms}) + (-60 \text{ volts}) = 0$$

$$(I \times 30 \text{ ohms}) = 60 \text{ volts}$$

$$I = \frac{60 \text{ volts}}{30 \text{ ohms}}$$

$$I = 2 \text{ amps}$$

Since the current obtained in the above calculations is a positive 2 amps, the assumed direction of current was correct. To show what happens if the incorrect direction of current is assumed, the problem will be solved as before, but with the opposite direction of current. The circuit is redrawn showing the new direction of current and new polarities in figure 3-25. Starting at point A the loop equation is:

$$E_3 + E_A + E_1 + E_2 = 0$$

$$(I \times R_3) + E_A + (I \times R_1) + (I \times R_2) = 0$$

Substituting Values:

$$(I \times 15 \text{ ohms}) + 60 \text{ volts} + (I \times 5 \text{ ohms}) + (I \times 10 \text{ ohms}) = 0$$

Combining like terms:

$$(I \times 30 \text{ ohms}) + 60 \text{ volts} = 0$$

$$I \times 30 \text{ ohms} = -60 \text{ volts}$$

$$I = \frac{-60 \text{ volts}}{30 \text{ ohms}}$$

$$I = -2 \text{ amps}$$

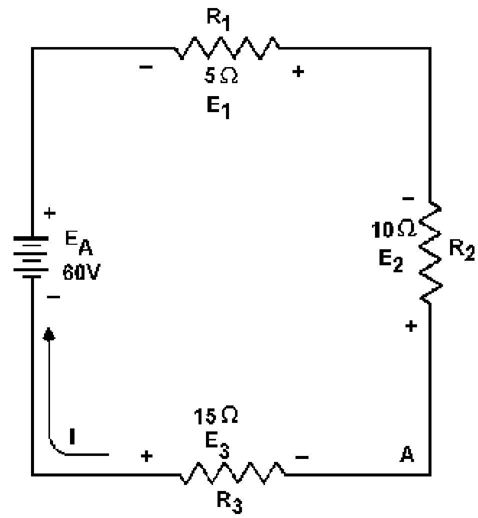


Figure 3-25.—Incorrect direction of assumed current.

Notice that the AMOUNT of current is the same as before. The polarity, however, is NEGATIVE. The negative polarity simply indicates the wrong direction of current was assumed. Should it be necessary to use this current in further calculations on the circuit using Kirchhoff's law, the negative polarity should be retained in the calculations.

Series Aiding and Opposing Sources

In many practical applications a circuit may contain more than one source of emf. Sources of emf that cause current to flow in the same direction are considered to be SERIES AIDING and the voltages are added. Sources of emf that would tend to force current in opposite directions are said to be SERIES OPPOSING, and the effective source voltage is the difference between the opposing voltages. When two opposing sources are inserted into a circuit current flow would be in a direction determined by the larger source. Examples of series aiding and opposing sources are shown in figure 3-26.

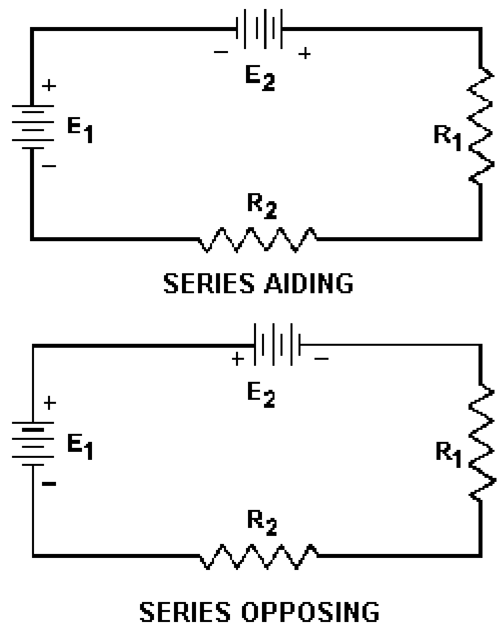


Figure 3-26.—Aiding and opposing sources.

A simple solution may be obtained for a multiple-source circuit through the use of Kirchhoff's voltage law. In applying this method, the same procedure is used for the multiple-source circuit as was used above for the single-source circuit. This is demonstrated by the following example.

Example: Using Kirchhoff's voltage equation, find the amount of current in the circuit shown in fig 3-27.

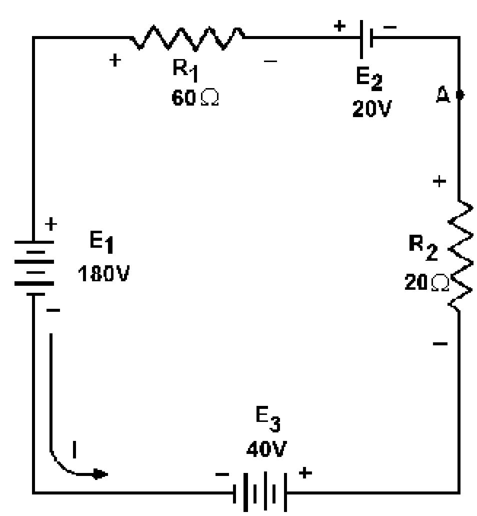


Figure 3-27.-Solving for circuit current using Kirchhoff's voltage equation.

Solution: As before, a direction of current flow is assumed and polarity signs are placed on the drawing. The loop equation will be started at point A.

$$E_2 + E_{R1} + E_1 + E_3 + E_{R2} = 0$$

$$20 \text{ volts} + (I \times 60 \text{ ohms}) + (-180 \text{ volts}) + 40 \text{ volts} + (I \times 20 \text{ ohms}) = 0$$

$$20 \text{ volts} - 180 \text{ volts} + 40 \text{ volts} + (I \times 60 \text{ ohms}) + (I \times 20 \text{ ohms}) = 0$$

$$-120 \text{ volts} + (I \times 80 \text{ ohms}) = 0$$

$$I \times 80 \text{ ohms} = 120 \text{ volts}$$

$$I = \frac{120 \text{ volts}}{80 \text{ ohms}}$$

$$I = 1.5 \text{ amps}$$

Q22. When using Kirchhoff's voltage law, how are voltage polarities assigned to the voltage drops across resistors?

Q23. Refer to figure 3-27, if R_1 was changed to a 40-ohm resistor, what would be the value of circuit current (I_T)?

Q24. Refer to figure 3-27. What is the effective source voltage of the circuit using the 40-ohm resistor?

CIRCUIT TERMS AND CHARACTERISTICS

Before you learn about the types of circuits other than the series circuit, you should become familiar with some of the terms and characteristics used in electrical circuits. These terms and characteristics will be used throughout your study of electricity and electronics.

REFERENCE POINT

A reference point is an arbitrarily chosen point to which all other points in the circuit are compared. In series circuits, any point can be chosen as a reference and the electrical potential at all other points can be determined in reference to that point. In figure 3-28 point A shall be considered the reference point. Each series resistor in the illustrated circuit is of equal value. The applied voltage is equally distributed across each resistor. The potential at point B is 25 volts more positive than at point A. Points C and D are 50 volts and 75 volts more positive than point A respectively.

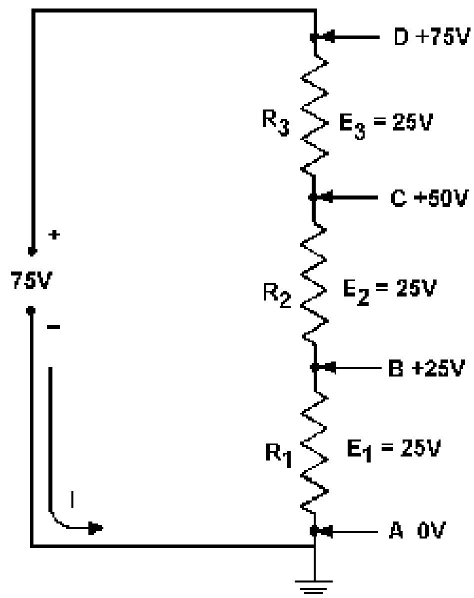


Figure 3-28.—Reference points in a series circuit.

When point B is used as the reference, as in figure 3-29, point D would be positive 50 volts in respect to the new reference point. The former reference point, A, is 25 volts negative in respect to point B.

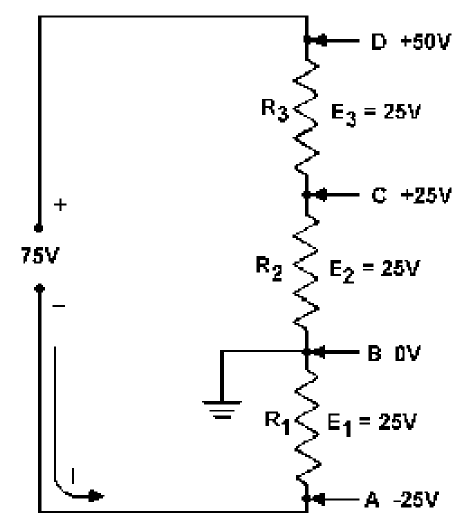


Figure 3-29.—Determining potentials with respect to a reference point.

As in the previous circuit illustration, the reference point of a circuit is always considered to be at zero potential. Since the earth (ground) is said to be at a zero potential, the term GROUND is used to denote a common electrical point of zero potential. In figure 3-30, point A is the zero reference, or ground, and the symbol for ground is shown connected to point A. Point C is 75 volts positive in respect to ground.

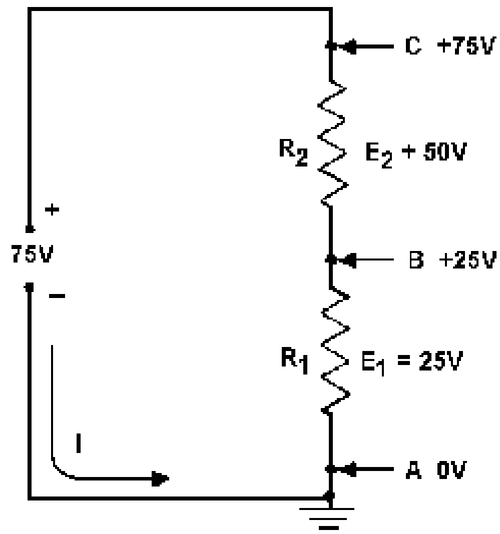


Figure 3-30.—Use of ground symbols.

In most electrical equipment, the metal chassis is the common ground for the many electrical circuits. When each electrical circuit is completed, common points of a circuit at zero potential are connected directly to the metal chassis, thereby eliminating a large amount of connecting wire. The electrons pass through the metal chassis (a conductor) to reach other points of the circuit. An example of a chassis grounded circuit is illustrated in figure 3-31.

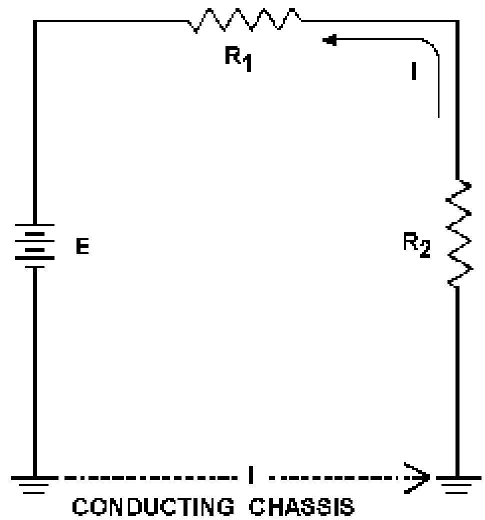


Figure 3-31.—Ground used as a conductor.

Most voltage measurements used to check proper circuit operation in electrical equipment are taken in respect to ground. One meter lead is attached to a grounded point and the other meter lead is moved to various test points. Circuit measurement is explained in more detail in NEETS Module 3.

OPEN CIRCUIT

A circuit is said to be OPEN when a break exists in a complete conducting pathway. Although an open occurs when a switch is used to deenergize a circuit, an open may also develop accidentally. To restore a circuit to proper operation, the open must be located, its cause determined, and repairs made.

Sometimes an open can be located visually by a close inspection of the circuit components. Defective components, such as burned out resistors, can usually be discovered by this method. Others, such as a break in wire covered by insulation or the melted element of an enclosed fuse, are not visible to the eye. Under such conditions, the understanding of the effect an open has on circuit conditions enables a technician to make use of test equipment to locate the open component.

In figure 3-32, the series circuit consists of two resistors and a fuse. Notice the effects on circuit conditions when the fuse opens.

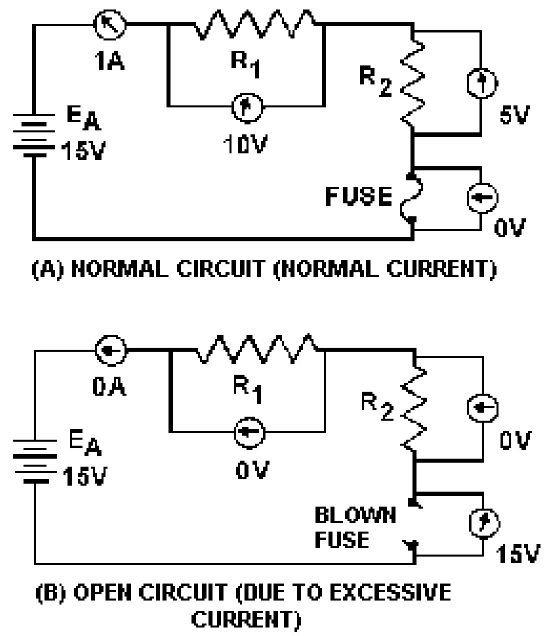


Figure 3-32.—Normal and open circuit conditions. (A) Normal current; (B) Excessive current.

Current ceases to flow; therefore, there is no longer a voltage drop across the resistors. Each end of the open conducting path becomes an extension of the battery terminals and the voltage felt across the open is equal to the applied voltage (E_A).

An open circuit has INFINITE resistance. INFINITY represents a quantity so large it cannot be measured. The symbol for infinity is ∞. In an open circuit, $R_T = \infty$.

SHORT CIRCUIT

A short circuit is an accidental path of low resistance which passes an abnormally high amount of current. A short circuit exists whenever the resistance of a circuit or the resistance of a part of a circuit drops in value to almost zero ohms. A short often occurs as a result of improper wiring or broken insulation.

In figure 3-33, a short is caused by improper wiring. Note the effect on current flow. Since the resistor has in effect been replaced with a piece of wire, practically all the current flows through the short and very little current flows through the resistor. Electrons flow through the short (a path of almost zero resistance) and the remainder of the circuit by passing through the 10-ohm resistor and the battery. The amount of current flow increases greatly because its resistive path has decreased from 10,010 ohms to 10 ohms. Due to the excessive current flow the 10-ohm resistor becomes heated. As it attempts to dissipate this heat, the resistor will probably be destroyed. Figure 3-34 shows a pictorial wiring diagram, rather than a schematic diagram, to indicate how broken insulation might cause a short circuit.

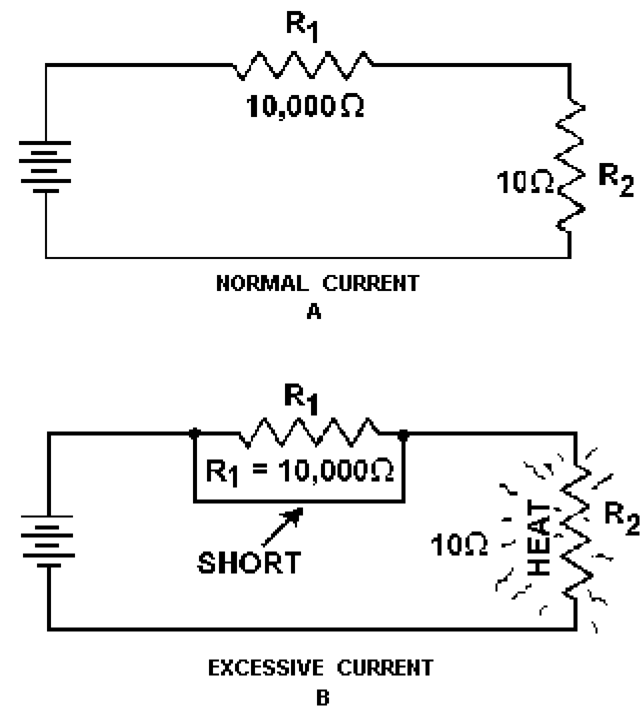


Figure 3-33.—Normal and short circuit conditions.

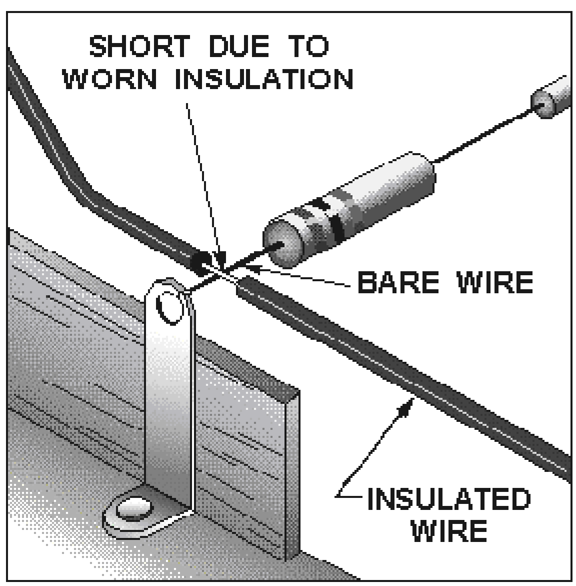


Figure 3-34.—Short due to broken insulation.

SOURCE RESISTANCE

A meter connected across the terminals of a good 1.5-volt battery reads about 1.5 volts. When the same battery is inserted into a complete circuit, the meter reading decreases to something less than 1.5 volts. This difference in terminal voltage is caused by the INTERNAL RESISTANCE of the battery (the opposition to current offered by the electrolyte in the battery). All sources of electromotive force have some form of internal resistance which causes a drop in terminal voltage as current flows through the source.

This principle is illustrated in figure 3-35, where the internal resistance of a battery is shown as R_i. In the schematic, the internal resistance is indicated by an additional resistor in series with the battery. The battery, with its internal resistance, is enclosed within the dotted lines of the schematic diagram. With the switch open, the voltage across the battery terminals reads 15 volts. When the switch is closed, current flow causes voltage drops around the circuit. The circuit current of 2 amperes causes a voltage drop of 2 volts across R_i. The 1-ohm internal battery resistance thereby drops the battery terminal voltage to 13 volts. Internal resistance cannot be measured directly with a meter. An attempt to do this would damage the meter.

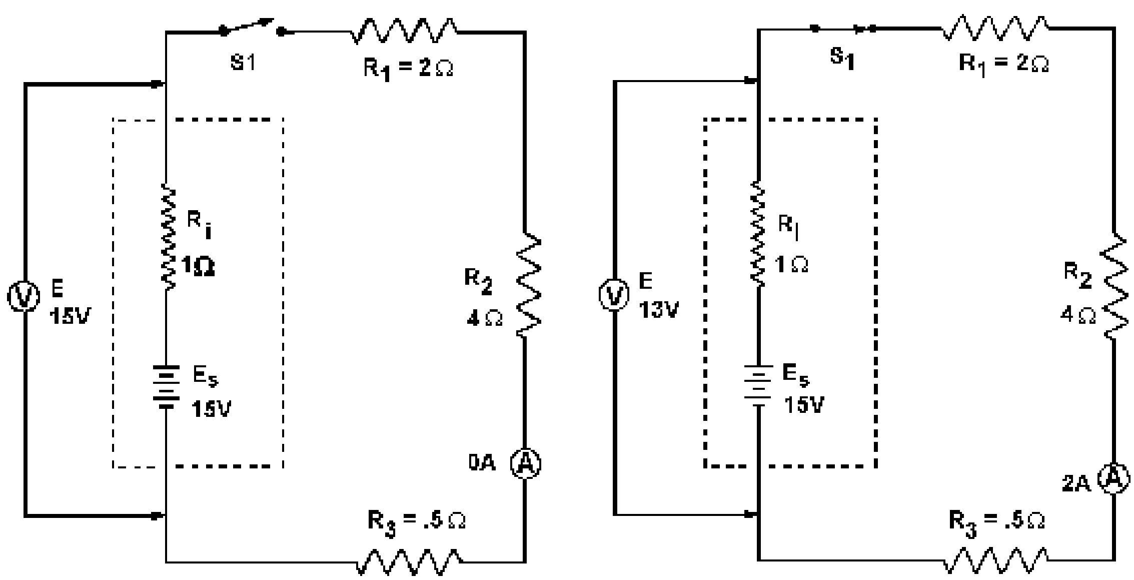
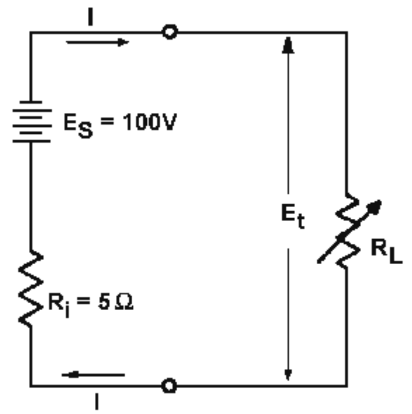


Figure 3-35.—Effect of internal resistance.

The effect of the source resistance on the power output of a dc source may be shown by an analysis of the circuit in figure 3-36. When the variable load resistor (R_L) is set at the zero-ohm position (equivalent to a short circuit), current (I) is calculated using the following formula:

$$I = \frac{E_S}{R_i} = \frac{100 \text{ volts}}{5 \text{ ohms}} = 20 \text{ amperes}$$

This is the maximum current that may be drawn from the source. The terminal voltage across the short circuit is zero volts and all the voltage is across the resistance within the source.

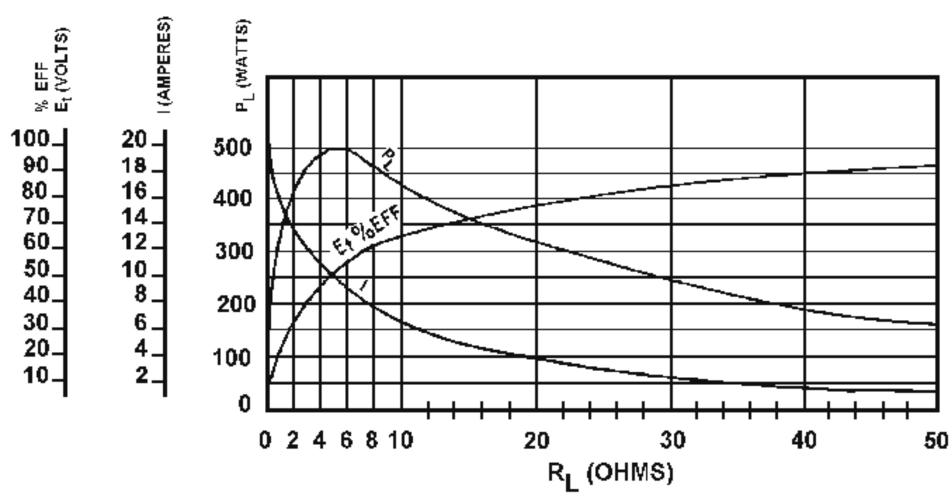


E_S = OPEN - CIRCUIT VOLTAGE OF SOURCE
R_i = INTERNAL RESISTANCE OF SOURCE
E_t = TERMINAL VOLTAGE
R_L = RESISTANCE OF LOAD
P_L = POWER USED IN LOAD
I = CURRENT FROM SOURCE
% EFF. = PERCENTAGE OF EFFICIENCY

(A)
CIRCUIT AND SYMBOL DESIGNATION

R_L	E_t	I	P_L	%EFF.
0	0	20	0	0
1	16.7	16.7	278.9	16.7
2	28.6	14.3	409	28.6
3	37.5	12.5	468.8	37.5
4	44.4	11.1	492.8	44.4
5	50	10	500	50
6	54.5	9.1	496.0	54.5
7	58.3	8.3	483.9	58.3
8	61.6	7.7	474.3	61.6
9	64.3	7.1	456.5	64.3
10	66.7	6.7	446.9	66.7
20	80	4	320	80
30	85.7	2.9	248.5	85.7
40	88.9	2.2	195.6	88.9
50	90.9	1.9	172.7	90.9

(B)
CHART



(C)
GRAPH

Figure 3-36.—Effect of source resistance on power output.

If the load resistance (R_L) were increased (the internal resistance remaining the same), the current drawn from the source would decrease. Consequently, the voltage drop across the internal resistance would decrease. At the same time, the terminal voltage applied across the load would increase and approach a maximum as the current approaches zero amps.

POWER TRANSFER AND EFFICIENCY

Maximum power is transferred from the source to the load when the resistance of the load is equal to the internal resistance of the source. This theory is illustrated in the table and the graph of figure 3-36. When the load resistance is 5 ohms, matching the source resistance, the maximum power of 500 watts is developed in the load.

The efficiency of power transfer (ratio of output power to input power) from the source to the load increases as the load resistance is increased. The efficiency approaches 100 percent as the load resistance approaches a relatively large value compared with that of the source, since less power is lost in the source. The efficiency of power transfer is only 50 percent at the maximum power transfer point (when the load resistance equals the internal resistance of the source). The efficiency of power transfer approaches zero efficiency when the load resistance is relatively small compared with the internal resistance of the source. This is also shown on the chart of figure 3-36.

The problem of a desire for both high efficiency and maximum power transfer is resolved by a compromise between maximum power transfer and high efficiency. Where the amounts of power involved are large and the efficiency is important, the load resistance is made large relative to the source resistance so that the losses are kept small. In this case, the efficiency is high. Where the problem of matching a source to a load is important, as in communications circuits, a strong signal may be more important than a high percentage of efficiency. In such cases, the efficiency of power transfer should be only about 50 percent; however, the power transfer would be the maximum which the source is capable of supplying.

You should now understand the basic concepts of series circuits. The principles which have been presented are of lasting importance. Once equipped with a firm understanding of series circuits, you hold the key to an understanding of the parallel circuits to be presented next.

Q25. A circuit has a source voltage of 100 volts and two 50-ohm resistors connected in series. If the reference point for this circuit is placed between the two resistors, what would be the voltage at the reference point?

Q26. If the reference point in question 25 were connected to ground, what would be the voltage level of the reference point?

Q27. What is an open circuit?

Q28. What is a short circuit?

Q29. Why will a meter indicate more voltage at the battery terminal when the battery is out of a circuit than when the battery is in a circuit?

Q30. What condition gives maximum power transfer from the source to the load?

Q31. What is the efficiency of power transfer in question 30?

Q32. A circuit has a source voltage of 25 volts. The source resistance is 1 ohm and the load resistance is 49 ohms. What is the efficiency of power transfer?

PARALLEL DC CIRCUITS

The discussion of electrical circuits presented up to this point has been concerned with series circuits in which there is only one path for current. There is another basic type of circuit known as the PARALLEL CIRCUIT with which you must become familiar. Where the series circuit has only one path for current, the parallel circuit has more than one path for current.

Ohm's law and Kirchhoff's law apply to all electrical circuits, but the characteristics of a parallel dc circuit are different than those of a series dc circuit.

PARALLEL CIRCUIT CHARACTERISTICS

A PARALLEL CIRCUIT is defined as one having more than one current path connected to a common voltage source. Parallel circuits, therefore, must contain two or more resistances which are not connected in series. An example of a basic parallel circuit is shown in figure 3-37.

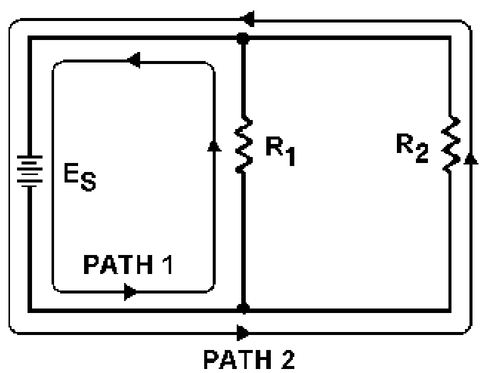


Figure 3-37.—Example of a basic parallel circuit.

Start at the voltage source (E_s) and trace counterclockwise around the circuit. Two complete and separate paths can be identified in which current can flow. One path is traced from the source, through resistance R_1, and back to the source. The other path is from the source, through resistance R_2, and back to the source.

Voltage in a Parallel Circuit

You have seen that the source voltage in a series circuit divides proportionately across each resistor in the circuit. IN A PARALLEL CIRCUIT, THE SAME VOLTAGE IS PRESENT IN EACH BRANCH. (A branch is a section of a circuit that has a complete path for current.) In figure 3-37 this voltage is equal to the applied voltage (E_s). This can be expressed in equation form as:

$$E_S = E_{R1} = E_{R2}$$

Voltage measurements taken across the resistors of a parallel circuit, as illustrated by figure 3-38 verify this equation. Each meter indicates the same amount of voltage. Notice that the voltage across each resistor is the same as the applied voltage.

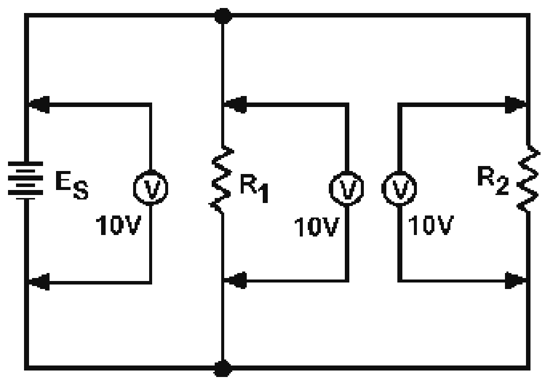


Figure 3-38.—Voltage comparison in a parallel circuit.

Example: Assume that the current through a resistor of a parallel circuit is known to be 4.5 milliamperes (4.5 mA) and the value of the resistor is 30,000 ohms (30 kΩ). Determine the source voltage. The circuit is shown in figure 3-39.

Given:

$$R_2 = 30{,}000 \text{ ohms } (30k\Omega)$$
$$I_{R2} = 4.5 \text{ milliamps } (4.5mA \text{ or } .0045 \text{ amps})$$

Solution:

$$E = IR$$
$$E_{R2} = .0045 \text{ amp} \times 30{,}000 \text{ ohms}$$
$$E_{R2} = 135 \text{ volts}$$

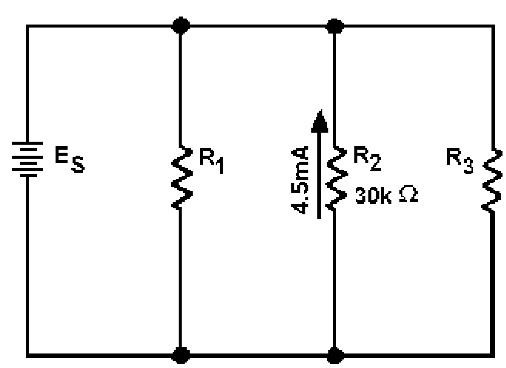


Figure 3-39.—Example problem parallel circuit.

Since the source voltage is equal to the voltage of a branch:

$$E_S = E_{R2}$$
$$E_S = 135 \text{ volts}$$

To simplify the math operation, the values can be expressed in powers of ten as follows:

$$30{,}000 \text{ ohms} = 30 \times 10^3 \text{ ohms}$$
$$4.5\text{mA} = 4.5 \times 10^{-3} \text{ amps}$$
$$E_{R2} = (4.5 \times 10^{-3}) \text{ amps} \times (30 \times 10^3) \text{ ohms}$$
$$E_{R2} = (4.5 \times 30 \times 10^{-3} \times 10^3) \text{ volts}$$
$$(10^{-3} \times 10^3 = 10^{-3+3} = 10^0 = 1)$$
$$E_{R2} = (4.5 \times 30 \times 1) \text{ volts}$$
$$E_{R2} = 135 \text{ volts}$$
$$E_S = E_{R2}$$
$$E_S = 135 \text{ volts}$$

If you are not familiar with the use of the powers of 10 or would like to brush up on it, Mathematics, Vol. 1, NAVEDTRA 10069-C, will be of great help to you.

Q33. What would the source voltage (E_S) in figure 3-39 be if the current through R_2 were 2 milliamps?

Current in a Parallel Circuit

Ohm's law states that the current in a circuit is inversely proportional to the circuit resistance. This fact is true in both series and parallel circuits.

There is a single path for current in a series circuit. The amount of current is determined by the total resistance of the circuit and the applied voltage. <u>In a parallel circuit the source current divides among the available paths.</u>

The behavior of current in parallel circuits will be shown by a series of illustrations using example circuits with different values of resistance for a given value of applied voltage.

Part (A) of figure 3-40 shows a basic series circuit. Here, the total current must pass through the single resistor. The amount of current can be determined.

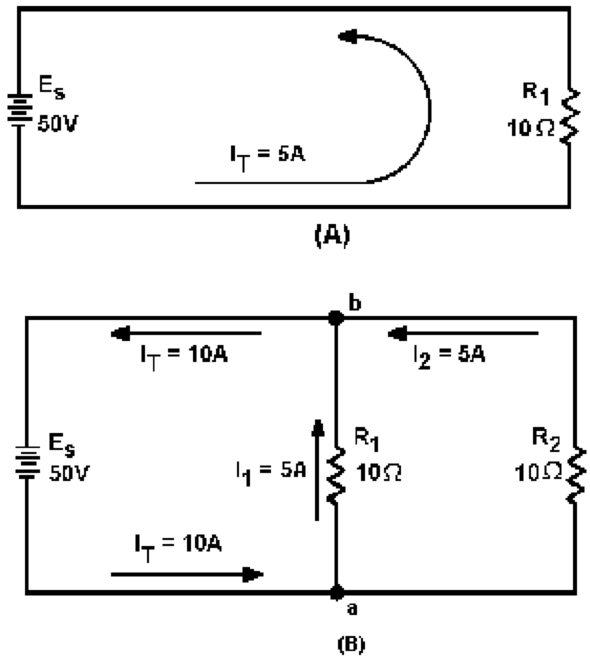


Figure 3-40.—Analysis of current in parallel circuit.

Given:

$$E_S = 50 \text{ volts}$$
$$R_1 = 10 \text{ ohms}$$

Solution:

$$I = \frac{E}{R}$$
$$I_T = \frac{E_S}{R_1}$$
$$I_T = \frac{50 \text{ volts}}{10 \text{ ohms}}$$
$$I_T = 5 \text{ amps}$$

Part (B) of figure 3-40 shows the same resistor (R_1) with a second resistor (R_2) of equal value connected in parallel across the voltage source. When Ohm's law is applied, the current flow through each resistor is found to be the same as the current through the single resistor in part (A).

Given:

$$E_S = 50 \text{ volts}$$
$$R_1 = 10 \text{ ohms}$$
$$R_2 = 10 \text{ ohms}$$

Solution:

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

$$E_S = E_{R1} = E_{R2}$$

$$I_{R1} = \frac{E_{R1}}{R_1}$$

$$I_{R1} = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_{R1} = 5 \text{ amps}$$

$$I_{R2} = \frac{E_{R2}}{R_2}$$

$$I_{R2} = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_{R2} = 5 \text{ amps}$$

It is apparent that if there is 5 amperes of current through each of the two resistors, there must be a TOTAL CURRENT of 10 amperes drawn from the source.

The total current of 10 amperes, as illustrated in figure 3-40(B), leaves the negative terminal of the battery and flows to point a. Since point a is a connecting point for the two resistors, it is called a JUNCTION. At junction a, the total current divides into two currents of 5 amperes each. These two currents flow through their respective resistors and rejoin at junction b. The total current then flows from junction b back to the positive terminal of the source. The source supplies a total current of 10 amperes and each of the two equal resistors carries one-half the total current.

Each individual current path in the circuit of figure 3-40(B) is referred to as a BRANCH. Each branch carries a current that is a portion of the total current. Two or more branches form a NETWORK.

From the previous explanation, the characteristics of current in a parallel circuit can be expressed in terms of the following general equation:

$$I_T = I_1 + I_2 + \ldots I_n$$

Compare part (A) of figure 3-41 with part (B) of the circuit in figure 3-40. Notice that doubling the value of the second branch resistor (R_2) has no effect on the current in the first branch (I_{R1}), but does reduce the second branch current (I_{R2}) to one-half its original value. The total circuit current drops to a value equal to the sum of the branch currents. These facts are verified by the following equations.

Given:

$$E_S = 50 \text{ volts}$$
$$R_1 = 10 \text{ ohms}$$
$$R_2 = 20 \text{ ohms}$$

Solution:

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

$$E_S = E_{R1} = E_{R2}$$

$$I = \frac{E_{R1}}{R_1}$$

$$I = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_{R1} = 5 \text{ amps}$$

$$I_{R2} = \frac{E_{R2}}{R_2}$$

$$I_{R2} = \frac{50 \text{ volts}}{20 \text{ ohms}}$$

$$I_{R2} = 2.5 \text{ amps}$$

$$I_T = I_{R1} + I_{R2}$$

$$I_T = 5 \text{ amps} + 2.5 \text{ amps}$$

$$I_T = 7.5 \text{ amps}$$

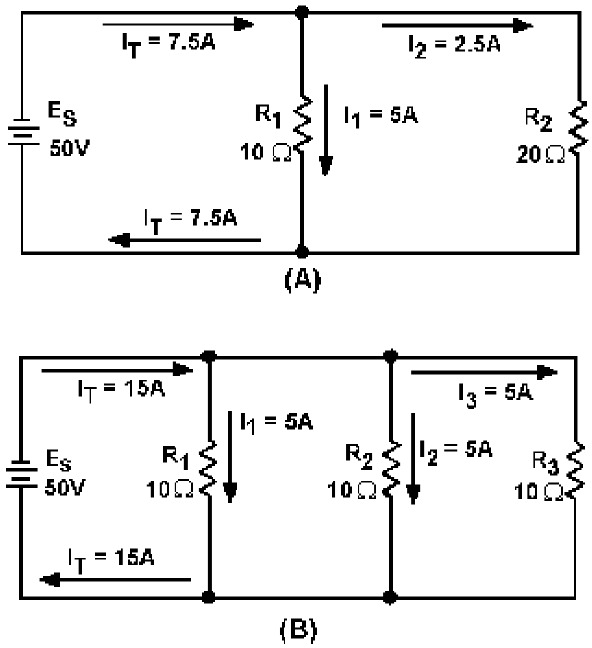


Figure 3-41.—Current behavior in parallel circuits.

The amount of current flow in the branch circuits and the total current in the circuit shown in figure 3-41(B) are determined by the following computations.

Given:

$$E_S = 50 \text{ volts}$$
$$R_1 = 10 \text{ ohms}$$
$$R_2 = 10 \text{ ohms}$$
$$R_3 = 10 \text{ ohms}$$

Solution:

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

$$E_S = E_{R1} = E_{R2} = E_{R3}$$

$$I_{R1} = \frac{E_{R1}}{R_1}$$

$$I_{R1} = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_{R1} = 5 \text{ amps}$$

$$I_{R2} = \frac{E_{R2}}{R_2}$$

$$I_{R2} = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_{R2} = 5 \text{ amps}$$

$$I_{R3} = \frac{E_{R3}}{R_3}$$

$$I_{R3} = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_{R3} = 5 \text{ amps}$$

$$I_T = I_{R1} + I_{R2} + I_{R3}$$

$$I_T = 5 \text{ amps} + 5 \text{ amps} + 5 \text{ amps}$$

$$I_T = 15 \text{ amps}$$

Notice that the sum of the ohmic values in each circuit shown in figure 3-41 is equal (30 ohms), and that the applied voltage is the same (50 volts). However, the total current in 3-41(B) (15 amps) is twice the amount in 3-41(A) (7.5 amps). It is apparent, therefore, that the manner in which resistors are connected in a circuit, as well as their actual ohmic values, affect the total current.

The division of current in a parallel network follows a definite pattern. This pattern is described by KIRCHHOFF'S CURRENT LAW which states:

"The algebraic sum of the currents entering and leaving any junction of conductors is equal to zero."

This law can be stated mathematically as:

$$I_a + l_b + \ldots I_n + 0$$

where: I_a, I_b, etc., are the currents entering and leaving the junction. Currents ENTERING the junction are considered to be POSITIVE and currents LEAVING the junction are considered to be NEGATIVE. When solving a problem using Kirchhoff's current law, the currents must be placed into the equation WITH THE PROPER POLARITY SIGNS ATTACHED.

Example: Solve for the value of I_3 in figure 3-42.

Given:

$$I_1 = 10 \text{ amps}$$
$$I_2 = 3 \text{ amps}$$
$$I_4 = 5 \text{ amps}$$

$$I_a + I_b + \ldots I_n = 0$$

Solution:

$$I_a + l_b + \ldots I_a + 0$$

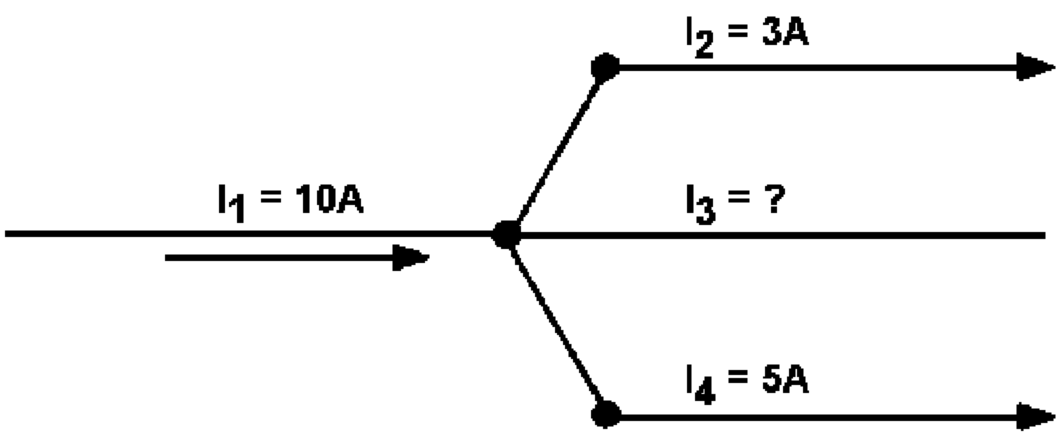


Figure 3-42.—Circuit for example problem.

The currents are placed into the equation with the proper signs.

$$I_1 + I_2 + I_3 + I_4 = 0$$
$$10 \text{ amps} + (-3 \text{ amps}) + I_3 + (-5 \text{ amps}) = 0$$
$$I_3 + 2 \text{ amps} = 0$$
$$I_3 = -2 \text{ amps}$$

I_3 has a value of 2 amperes, and the negative sign shows it to be a current LEAVING the junction.

Example. Using figure 3-43, solve for the magnitude and direction of I_3.

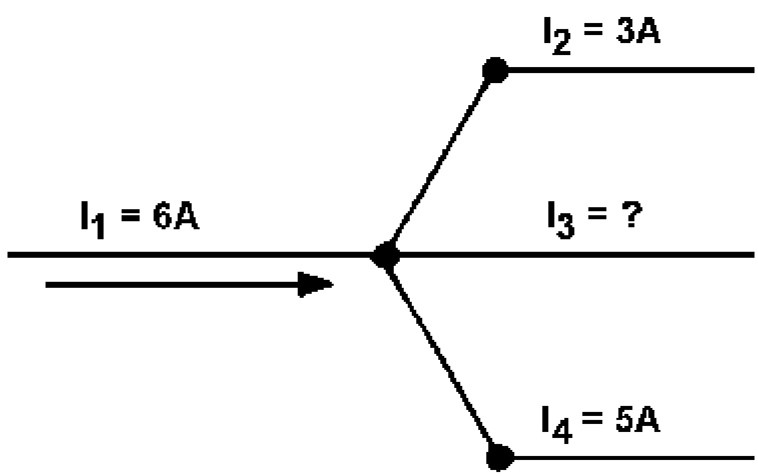


Figure 3-43.—Circuit for example problem.

Given:

$$I_1 = 6 \text{ amps}$$
$$I_2 = 3 \text{ amps}$$
$$I_4 = 5 \text{ amps}$$

Solution:

$$I_a + I_b + \ldots I_n = 0$$

$$I_1 + I_2 + I_3 + I_4 = 0$$

$$6 \text{ amps} + (-3 \text{ amps}) + I_3 + (-5 \text{ amps}) = 0$$

$$I_3 + (-2 \text{ amps}) = 0$$

$$I_3 = -2 \text{ amps}$$

I_3 is 2 amperes and its positive sign shows it to be a current entering the junction.

Q34. There is a relationship between total current and current through the individual components in a circuit. What is this relationship in a series circuit and a parallel circuit?

Q35. In applying Kirchhoff's current law, what does the polarity of the current indicate?

Resistance in a Parallel Circuit

In the example diagram, figure 3-44, there are two resistors connected in parallel across a 5-volt battery. Each has a resistance value of 10 ohms. A complete circuit consisting of two parallel paths is formed and current flows as shown.

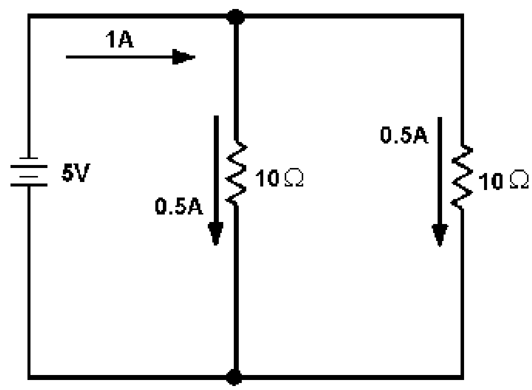


Figure 3-44.—Two equal resistors connected in parallel.

Computing the individual currents shows that there is one-half of an ampere of current through each resistance. The total current flowing from the battery to the junction of the resistors, and returning from the resistors to the battery, is equal to 1 ampere.

The total resistance of the circuit can be calculated by using the values of total voltage (E_T) and total current (I_T).

NOTE: From this point on the abbreviations and symbology for electrical quantities will be used in example problems.

Given:

$$E_T = 5\ V$$
$$I_T = 1\ A$$

Solution:

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

$$R_T = \frac{E_T}{I_T}$$

$$R_T = \frac{5\ V}{1\ A}$$

$$R_T = 5\ \Omega$$

This computation shows the total resistance to be 5 ohms; one-half the value of either of the two resistors.

Since the total resistance of a parallel circuit is smaller than any of the individual resistors, total resistance of a parallel circuit is not the sum of the individual resistor values as was the case in a series circuit. The total resistance of resistors in parallel is also referred to as EQUIVALENT RESISTANCE (R_{eq}). The terms total resistance and equivalent resistance are used interchangeably.

There are several methods used to determine the equivalent resistance of parallel circuits. The best method for a given circuit depends on the number and value of the resistors. For the circuit described above, where all resistors have the same value, the following simple equation is used:

$$R_{eq} = \frac{R}{N}$$

R_{eq} = equivalent parallel resistance

R = ohmic value of one resistor

N = number of resistors

This equation is valid for any number of parallel resistors of EQUAL VALUE.

Example: Four 40-ohm resistors are connected in parallel. What is their equivalent resistance?

Given:

$$R_1 + R_2 + R_3 + R_4$$

$$R_1 = 40\ \Omega$$

Solution:

$$R_{eq} = \frac{R}{N}$$

$$R_{eq} = \frac{40\Omega}{4}$$

$$R_{eq} = 10\ \Omega$$

Figure 3-45 shows two resistors of unequal value in parallel. Since the total current is shown, the equivalent resistance can be calculated.

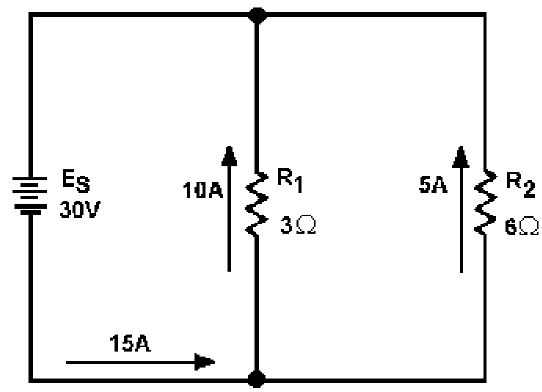


Figure 3-45.—Example circuit with unequal parallel resistors.

Given:

$$E_S = 30\ V$$
$$I_T = 15\ A$$

Solution:

$$R_{eq} = \frac{E_S}{I_T}$$

$$R_{eq} = \frac{30\ V}{15\ A}$$

$$R_{eq} = 2\ \Omega$$

The equivalent resistance of the circuit shown in figure 3-45 is smaller than either of the two resistors (R_1, R_2). An important point to remember is that the equivalent resistance of a parallel circuit is always less than the resistance of any branch.

Equivalent resistance can be found if you know the individual resistance values and the source voltage. By calculating each branch current, adding the branch currents to calculate total current, and dividing the source voltage by the total current, the total can be found. This method, while effective, is somewhat lengthy. A quicker method of finding equivalent resistance is to use the general formula for resistors in parallel:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \frac{1}{R_n}$$

If you apply the general formula to the circuit shown in figure 3-45 you will get the same value for equivalent resistance (2Ω) as was obtained in the previous calculation that used source voltage and total current.

Given:

$$R_1 = 3\Omega$$
$$R_2 = 6\Omega$$

Solution:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$
$$\frac{1}{R_{eq}} = \frac{1}{3\Omega} + \frac{1}{6\Omega}$$

Convert the fractions to a common denominator.

$$\frac{1}{R_{eq}} = \frac{2}{6\Omega} + \frac{1}{6\Omega}$$
$$\frac{1}{R_{eq}} = \frac{3}{6\Omega}$$
$$\frac{1}{R_{eq}} = \frac{1}{2\Omega}$$

Since both sides are reciprocals (divided into one), disregard the reciprocal function.

$$R_{eq} = 2\Omega$$

The formula you were given for equal resistors in parallel

$$\left(R_{eq} = \frac{R}{N} \right)$$

is a simplification of the general formula for resistors in parallel

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \frac{1}{R_n}$$

There are other simplifications of the general formula for resistors in parallel which can be used to calculate the total or equivalent resistance in a parallel circuit.

RECIPROCAL METHOD.—This method is based upon taking the reciprocal of each side of the equation. This presents the general formula for resistors in parallel as:

$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \ldots \frac{1}{R_n}}$$

This formula is used to solve for the equivalent resistance of a number of unequal parallel resistors. You must find the lowest common denominator in solving these problems. If you are a little hazy on finding the lowest common denominator, brush up on it in *Mathematics Volume 1*, NAVEDTRA 10069 (Series).

Example: Three resistors are connected in parallel as shown in figure 3-46. The resistor values are: R_1 = 20 ohms, R_2 = 30 ohms, R_3 = 40 ohms. What is the equivalent resistance? (Use the reciprocal method.)

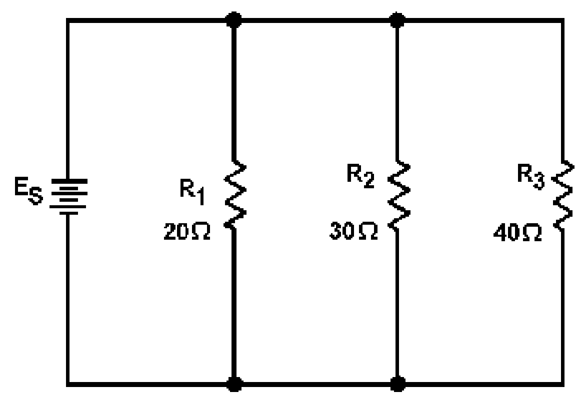


Figure 3-46.—Example parallel circuit with unequal branch resistors.

Given:

$$R_1 = 20\Omega$$
$$R_2 = 30\Omega$$
$$R_3 = 40\Omega$$

Solution:

$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R3}}$$

$$R_{eq} = \frac{1}{\frac{1}{20\Omega} + \frac{1}{30\Omega} + \frac{1}{40\Omega}}$$

$$R_{eq} = \frac{1}{\frac{6}{120\Omega} + \frac{4}{120\Omega} + \frac{3}{120\Omega}}$$

$$R_{eq} = \frac{1}{\frac{13}{120}\Omega}$$

$$R_{eq} = \frac{120}{13}\Omega$$

$$R_{eq} = 9.23\Omega$$

PRODUCT OVER THE SUM METHOD.—A convenient method for finding the equivalent, or total, resistance of two parallel resistors is by using the following formula.

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$$

This equation, called the product over the sum formula, is used so frequently it should be committed to memory.

Example: What is the equivalent resistance of a 20-ohm and a 30-ohm resistor connected in parallel, as in figure 3-47?

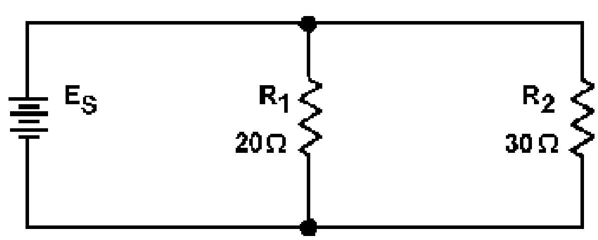


Figure 3-47.—Parallel circuit with two unequal resistors.

Given:

$$R_1 = 20\Omega$$
$$R_2 = 30\Omega$$

Solution:

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$$
$$R_{eq} = \frac{20\Omega \times 30\Omega}{20\Omega + 30\Omega}$$
$$R_{eq} = \frac{600}{50}\Omega$$
$$R_{eq} = 12\Omega$$

Q36. Four equal resistors are connected in parallel, each resistor has an ohmic value of 100 ohms, what is the equivalent resistance?

Q37. Three resistors connected in parallel have values of 12 kΩ, 20 kΩ, and 30 kΩ. What is the equivalent resistance?

Q38. Two resistors connected in parallel have values of 10 kΩ and 30 kΩ. What is the equivalent resistance?

Power in a Parallel Circuit

Power computations in a parallel circuit are essentially the same as those used for the series circuit. Since power dissipation in resistors consists of a heat loss, power dissipations are additive regardless of how the resistors are connected in the circuit. The total power is equal to the sum of the power dissipated by the individual resistors. Like the series circuit, the total power consumed by the parallel circuit is:

$$P_T = P_1 + P_2 + \ldots P_n$$

Example: Find the total power consumed by the circuit in figure 3-48.

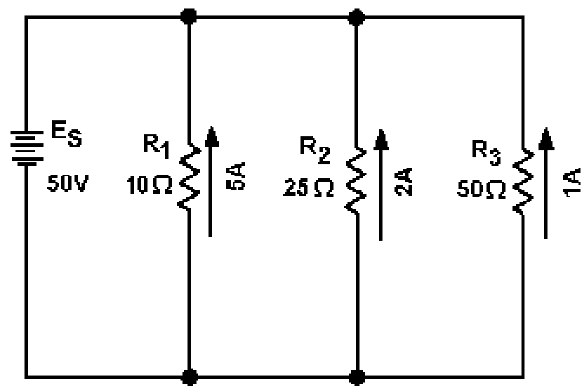


Figure 3-48.—Example parallel circuit.

Given:

$$R_1 = 10\ \Omega$$
$$I_{R1} = 5A$$

$$R_2 = 25\ \Omega$$
$$I_{R2} = 2A$$

$$R_3 = 50\ \Omega$$
$$I_{R3} = 1A$$

Solution:

$$P = I^2R$$
$$P_{R1} = (I_{R1})^2 \times R_1$$
$$P_{R1} = (5\ A)^2 \times 10\Omega$$
$$P_{R1} = 250W$$

$$P_{R2} = (I_{R2})^2 \times R_2$$
$$P_{R2} = (2\ A)^2 \times 25\Omega$$
$$P_{R2} = 100W$$

$$P_{R3} = (I_{R3})^2 \times R_3$$
$$P_{R3} = (1\ A)^2 \times 50\Omega$$
$$P_{R3} = 50W$$

$$P_T = P_{R1} + P_{R2} + P_{R3}$$
$$P_T = 250W + 100W + 50W$$
$$P_T = 400W$$

Since the total current and source voltage are known, the total power can also be computed by:

Given:

$$E_S = 50\ V$$
$$I_T = 8\ A$$

Solution:

$$P_T = E_S \times I_T$$
$$P_T = 50\ V \times 8\ A$$
$$P_T = 400W$$

Equivalent Circuits

In the study of electricity, it is often necessary to reduce a complex circuit into a simpler form. Any complex circuit consisting of resistances can be redrawn (reduced) to a basic equivalent circuit containing the voltage source and a single resistor representing total resistance. This process is called reduction to an EQUIVALENT CIRCUIT.

Figure 3-49 shows a parallel circuit with three resistors of equal value and the redrawn equivalent circuit. The parallel circuit shown in part A shows the original circuit. To create the equivalent circuit, you must first calculate the equivalent resistance.

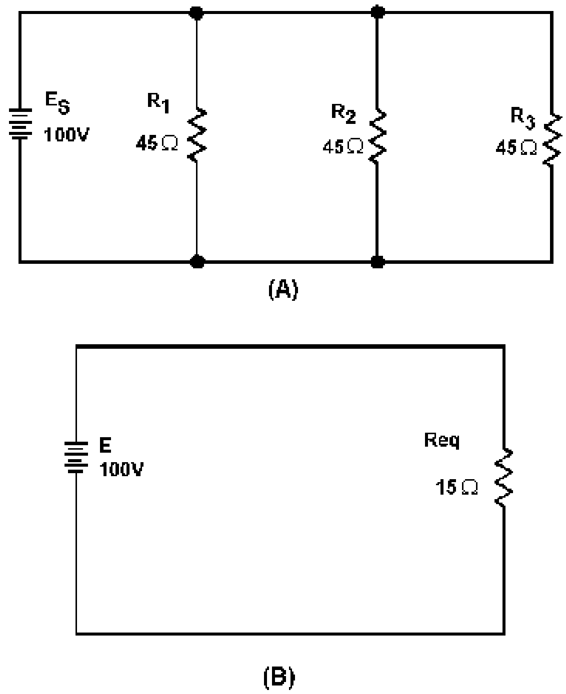


Figure 3-49.—Parallel circuit with equivalent circuit.

Given:

$$R_1 = 45\Omega$$
$$R_2 = 45\Omega$$
$$R3 = 45\Omega$$

Solution:

$$R_{eq} = \frac{R}{N}$$
$$R_{eq} = \frac{45\Omega}{3}$$
$$R_{eq} = 15\ \Omega$$

Once the equivalent resistance is known, a new circuit is drawn consisting of a single resistor (to represent the equivalent resistance) and the voltage source, as shown in part B.

Rules for Parallel DC Circuits

1. The same voltage exists across each branch of a parallel circuit and is equal to the source voltage.

2. The current through a branch of a parallel network is inversely proportional to the amount of resistance of the branch.

3. The total current of a parallel circuit is equal to the sum of the individual branch currents of the circuit.

4. The total resistance of a parallel circuit is found by the general formula:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots \frac{1}{R_n}$$

or one of the formulas derived from this general formula.

5. The total power consumed in a parallel circuit is equal to the sum of the power consumptions of the individual resistances.

SOLVING PARALLEL CIRCUIT PROBLEMS

Problems involving the determination of resistance, voltage, current, and power in a parallel circuit are solved as simply as in a series circuit. The procedure is the same — (1) draw the circuit diagram, (2) state the values given and the values to be found, (3) select the equations to be used in solving for the unknown quantities based upon the known quantities, and (4) substitute the known values in the equation you have selected and solve for the unknown value.

Example: A parallel circuit consists of five resistors. The value of each resistor is known and the current through R_1 is known. You are asked to calculate the value for total resistance, total power, total current, source voltage, the power used by each resistor, and the current through resistors R_2, R_3, R_4, and R_5.

Given:

$$R_1 = 20\Omega$$
$$R_2 = 30\Omega$$
$$R_3 = 18\Omega$$
$$R_4 = 18\Omega$$
$$R_5 = 18\Omega$$
$$I_{R1} = 9A$$

Find:

$$R_T, E_S, I_T, P_T, I_{R2}, I_{R3}, I_{R4},$$
$$I_{R5}, P_{R1}, P_{R2}, P_{R3}, P_{R4}, P_{R5}$$

This may appear to be a large amount of mathematical manipulation. However, if you use the step-by-step approach, the circuit will fall apart quite easily.

The first step in solving this problem is for you to draw the circuit and indicate the known values as shown in figure 3-50.

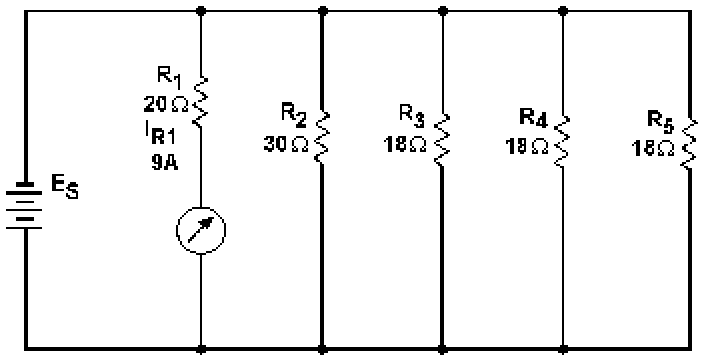


Figure 3-50.—Parallel circuit problem.

There are several ways to approach this problem. With the values you have been given, you could first solve for R_T, the power used by R_1, or the voltage across R_1, which you know is equal to the source voltage and the voltage across each of the other resistors. Solving for R_T or the power used by R_1 will not help in solving for the other unknown values.

Once the voltage across R_1 is known, this value will help you calculate other unknowns. Therefore the logical unknown to solve for is the source voltage (the voltage across R_1).

Given:

$$R_1 = 20\Omega$$
$$I_{R1} = 9A$$
$$E_{R1} = E_S$$

Solution:

$$E_S = R_1 \times I_{R1}$$
$$E_S = 9A \times 20\Omega$$
$$E_S = 180V$$

Now that source voltage is known, you can solve for current in each branch.

Given:

$$E_S = 180V$$
$$R_2 = 30\Omega$$
$$R_3 = 18\Omega$$
$$R_4 = 18\Omega$$
$$R_5 = 18\Omega$$

Solution:

$$I_{R2} = \frac{E_S}{R_2}$$

$$I_{R2} = \frac{180\ V}{30\ \Omega}$$

$$I_{R2} = 6\ A$$

$$I_{R3} = \frac{E_S}{R_3}$$

$$I_{R3} = \frac{180\ V}{18\ \Omega}$$

$$I_{R3} = 10\ A$$

Since $R_3 = R_4 = R_5$ and the voltage across each branch is the same:

$$I_{R4} = 10A$$
$$I_{R5} = 10A$$

Solving for total resistance.

Given:

$$R_1 = 20\Omega$$
$$R_2 = 30\Omega$$
$$R_3 = 18\Omega$$
$$R_4 = 18\Omega$$
$$R_5 = 18\Omega$$

Solution:

$$R_T = R_{eq}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}$$

$$\frac{1}{R_T} = \frac{1}{20\Omega} + \frac{1}{30\Omega} + \frac{1}{18\Omega} + \frac{1}{18\Omega} + \frac{1}{18\Omega}$$

$$\frac{1}{R_T} = \frac{9 + 6 + 10 + 10 + 10\Omega}{180 \quad (LCD)}$$

$$R_T = \frac{45\Omega}{180}$$

$$R_T = \frac{180}{45\Omega}$$

$$R_T = 4\Omega$$

An alternate method for solving for R_T can be used. By observation, you can see that R_3, R_4, and R_5 are of equal ohmic value. Therefore an equivalent resistor can be substituted for these three resistors in solving for total resistance.

Given:

$$R_3 = R_4 = R_5 = 18\Omega$$

Solution:

$$R_{eq1} = \frac{R}{N}$$

$$R_{eq1} = \frac{18\Omega}{3}$$

$$R_{eq1} = 6\Omega$$

The circuit can now be redrawn using a resistor labeled R_{eq1} in place of R_3, R_4, and R_5 as shown in figure 3-51.

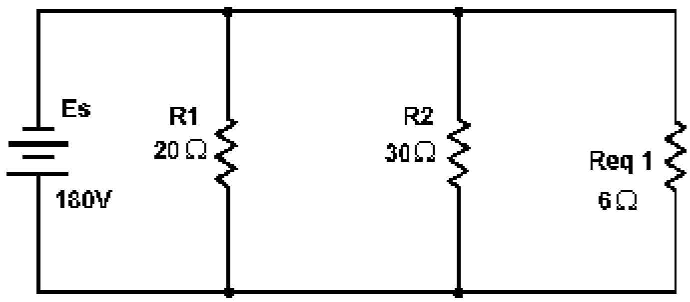


Figure 3-51.—First equivalent parallel circuit.

An equivalent resistor can be calculated and substituted for R_1 and R_2 by use of the product over the sum formula.

Given:

$$R_1 = 20\Omega$$
$$R_2 = 30\Omega$$

Solution:

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$$
$$R_{eq\,2} = \frac{20\Omega \times 30\Omega}{20\Omega + 30\Omega}$$
$$R_{eq\,2} = \frac{600}{50}\Omega$$
$$R_{eq\,2} = 12\Omega$$

The circuit is now redrawn again using a resistor labeled R_{eq2} in place of R_1 and R_2 as shown in figure 3-52.

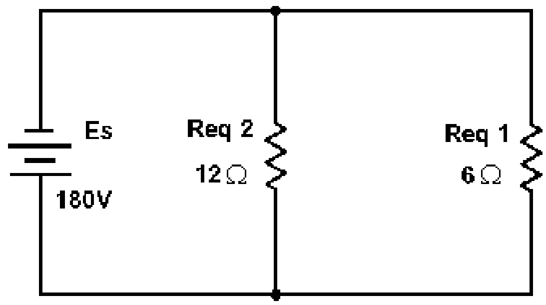


Figure 3-52.—Second equivalent parallel circuit.

You are now left with two resistors in parallel. The product over the sum method can now be used to solve for total resistance.

Given:

$$R_{eq1} = 6\Omega$$
$$R_{eq1} = 12\Omega$$
$$R_T = R_{eq}$$

Solution:

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_T = \frac{R_{eq1} \times R_{eq2}}{R_{eq1} + R_{eq2}}$$

$$R_T = \frac{6\Omega \times 12\Omega}{6\Omega + 12\Omega}$$

$$R_T = \frac{72}{18}\Omega$$

$$R_T = 4\Omega$$

This agrees with the solution found by using the general formula for solving for resistors in parallel.

The circuit can now be redrawn as shown in figure 3-53 and total current can be calculated.

Figure 3-53.—Parallel circuit redrawn to final equivalent circuit.

Given:

$$E_S = 180V$$
$$R_T = 4\Omega$$

Solution:

$$I_T = \frac{E_S}{R_T}$$
$$I_T = \frac{180V}{4\Omega}$$
$$I_T = 45A$$

This solution can be checked by using the values already calculated for the branch currents.

Given:

$$I_{R1} = 9A$$
$$I_{R2} = 6A$$
$$I_{R3} = 10A$$
$$I_{R4} = 10A$$
$$I_{R5} = 10A$$

Solution:

$$I_T = I_{R1} + I_{R2} + \ldots I_{Rn}$$
$$I_T = 9A + 6A + 10A + 10A + 10A$$
$$I_T = 45A$$

Now that total current is known, the next logical step is to find total power.

Given:

$$E_S = 180V$$
$$I_T = 45A$$

Solution:

$$P = EI$$
$$P_T = E_S \times I_T$$
$$P_T = 180V \times 45A$$
$$P_T = 8100 \text{ watts} = 8.1\text{ kW}$$

Solving for the power in each branch.

Given:

$$E_S = 180V$$
$$I_{R1} = 9A$$
$$I_{R2} = 6A$$
$$I_{R3} = 10A$$
$$I_{R4} = 10A$$
$$I_{R5} = 10A$$

Solution:

$$P = EI$$
$$P_{R1} = E_S \times I_{R1}$$
$$P_{R1} = 180V \times 9A$$
$$P_{R1} = 1620W$$

$$P_{R2} = E_S \times I_{R2}$$
$$P_{R2} = 180V \times 6A$$
$$P_{R2} = 1080W$$

$$P_{R3} = E_S \times I_{R3}$$
$$P_{R3} = 180V \times 10A$$
$$P_{R3} = 1800W$$

Since $I_{R3} = I_{R4} = I_{R5}$ then, $P_{R3} = P_{R4} = P_{R5} = 1800$ W. The previous calculation for total power can now be checked.

Given:

$$P_{R1} = 1620W$$
$$P_{R2} = 1080W$$
$$P_{R3} = 1800W$$
$$P_{R4} = 1800W$$
$$P_{R5} = 1800W$$

Solution:

$$P_T = P_{R1} + P_{R2} + P_{R3} + P_{R4} + P_{R5}$$
$$P_T = 1620W + 1080W + 1800W + 1800W + 1800W$$
$$P_T = 8100W$$
$$P_T = 8.1kW$$

Q39. What term identifies a single resistor that represents total resistance of a complex circuit?

Q40. The total power in both series and parallel circuits is computed with the formula: $P_T = P_1 + P_2 + P_3 + ...P_n$. Why can this formula be used for both series and parallel circuits?

Q41. A circuit consists of three resistors connected in parallel across a voltage source. $R_l = 40\Omega$, $R_2 = 30\Omega$, $R_3 = 40\Omega$, and $P_{R3} = 360$ watts. Solve for R_T, E_S and I_{R2}. (Hint: Draw and label the circuit first.)

SERIES-PARALLEL DC CIRCUITS

In the preceding discussions, series and parallel dc circuits have been considered separately. The technician will encounter circuits consisting of both series and parallel elements. A circuit of this type is referred to as a COMBINATION CIRCUIT. Solving for the quantities and elements in a combination circuit is simply a matter of applying the laws and rules discussed up to this point.

SOLVING COMBINATION-CIRCUIT PROBLEMS

The basic technique used for solving dc combination-circuit problems is the use of equivalent circuits. To simplify a complex circuit to a simple circuit containing only one load, equivalent circuits are substituted (on paper) for the complex circuit they represent. To demonstrate the method used to solve combination circuit problems, the network shown in figure 3-54(A) will be used to calculate various circuit quantities, such as resistance, current, voltage, and power.

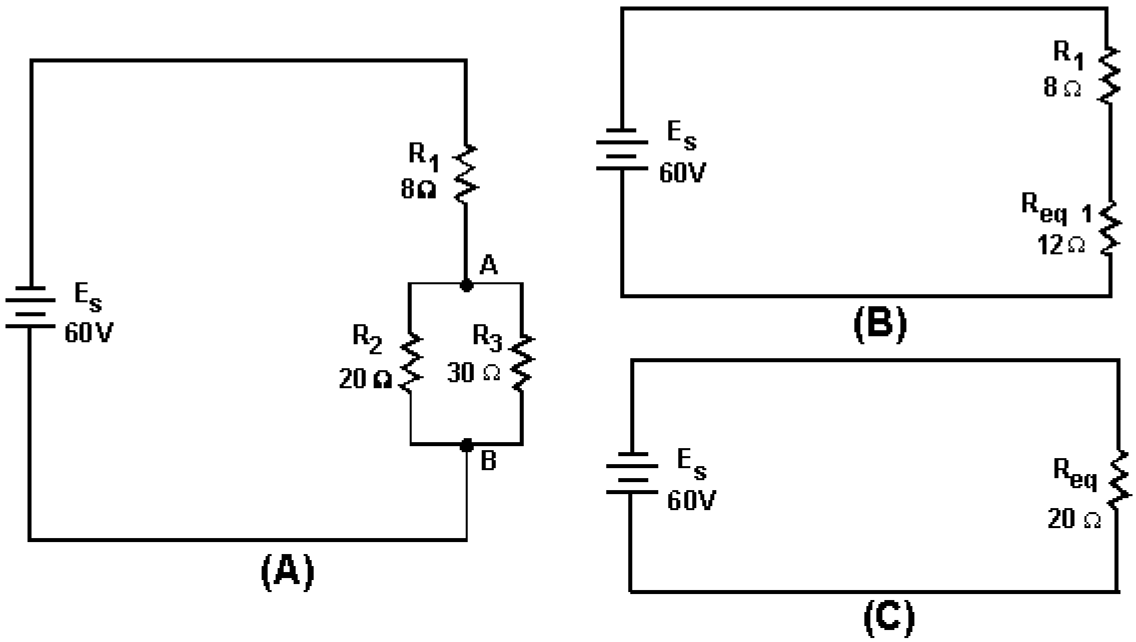


Figure 3-54.—Example combination circuit.

Examination of the circuit shows that the only quantity that can be computed with the given information is the equivalent resistance of R_2 and R_3.

Given:

$$R_2 = 20\Omega$$
$$R_3 = 30\Omega$$

Solution:

$$R_{eq1} = \frac{R_2 \times R_3}{R_2 + R_3} \quad \text{(Product over the sum)}$$

$$R_{eq1} = \frac{20\Omega \times 30\Omega}{20\Omega + 30\Omega}$$

$$R_{eq1} = \frac{600}{50}\Omega$$

$$R_{eq1} = 12\Omega$$

Now that the equivalent resistance for R_2 and R_3 has been calculated, the circuit can be redrawn as a series circuit as shown in figure 3-54(B).

The equivalent resistance of this circuit (total resistance) can now be calculated.

Given:

$$R_1 = 8\Omega \quad \text{(Resistors in series)}$$
$$R_{eq1} = 12\Omega$$

Solution:

$$R_{eq} = R_1 + R_{eq1}$$
$$R_{eq} = 8\Omega + 12\Omega$$
$$R_{eq} = 20\Omega$$
or
$$R_T = 20\Omega$$

The original circuit can be redrawn with a single resistor that represents the equivalent resistance of the entire circuit as shown in figure 3-54(C).

To find total current in the circuit:

Given:

$$E_S = 60V$$
$$R_T = 20\Omega$$

Solution:

$$I_T = \frac{E_S}{R_T}$$
$$I_T = \frac{60V}{20\Omega} \quad \text{(Ohm's Law)}$$
$$I_T = 3A$$

To find total power in the circuit:

Given:

$$E_S = 60V$$
$$I_T = 3A$$

Solution:

$$P_T = E_S \times I_T$$
$$P_T = 60V \times 3A$$
$$P_T = 180W$$

To find the voltage dropped across R_l, R_2, and R_3, refer to figure 3-54(B). R_{eq1} represents the parallel network of R_2 and R_3. Since the voltage across each branch of a parallel circuit is equal, the voltage across R_{eq1} (E_{eq1}) will be equal to the voltage across R_2 (E_{R2}) and also equal to the voltage across R_3 (E_{R3}).

Given:

$$I_T = 3A \quad \text{(Current through each part of a series circuit is equal to total current)}$$
$$R_1 = 8\Omega$$
$$R_{eq1} = 12\Omega$$

Solution:

$$E_{R1} = I_1 \times R_1$$
$$E_{R1} = 3A \times 8\Omega$$
$$E_{R1} = 24V$$
$$E_{R2} = E_{R3} = E_{eq1}$$
$$E_{eq1} = I_T \times R_{eq1}$$
$$E_{eq1} = 3A \times 12\Omega$$
$$E_{eq1} = 36V$$
$$E_{R2} = 36V$$
$$E_{R3} = 36V$$

To find power used by R_l:

Given:

$$E_{R1} = 24V$$
$$I_T = 3A$$

Solution:

$$P_{R1} = E_{R1} \times I_T$$
$$P_{R1} = 24V \times 3A$$
$$P_{R1} = 72W$$

To find the current through R_2 and R_3, refer to the original circuit, figure 3-54(A). You know E_{R2} and E_{R3} from previous calculation.

Given:

$$E_{R2} = 36V$$
$$E_{R3} = 36V$$
$$R_2 = 20\Omega$$
$$R_2 = 30\Omega$$

Solution:

$$I_{R2} = \frac{E_{R2}}{R_2} \quad \text{(Ohm's Law)}$$

$$I_{R2} = \frac{36V}{20\Omega}$$

$$I_{R2} = 1.8A$$

$$I_{R3} = \frac{E_{R3}}{R_3}$$

$$I_{R3} = \frac{36V}{30\Omega}$$

$$I_{R3} = 1.2A$$

To find power used by R_2 and R_3, using values from previous calculations:

Given:

$$E_{R2} = 36V$$
$$E_{R3} = 36V$$
$$I_{R2} = 1.8A$$
$$I_{R2} = 1.2A$$

Solution:

$$P_{R2} = E_{R2} \times I_{R2}$$
$$P_{R2} = 36V \times 1.8A$$
$$P_{R2} = 64.8W$$

$$P_{R3} = E_{R3} \times I_{R3}$$
$$P_{R3} = 36V \times 1.2A$$
$$P_{R3} = 43.2W$$

Now that you have solved for the unknown quantities in this circuit, you can apply what you have learned to any series, parallel, or combination circuit. It is important to remember to first look at the circuit and from observation make your determination of the type of circuit, what is known, and what you are looking for. A minute spent in this manner may save you many unnecessary calculations.

Having computed all the currents and voltages of figure 3-54, a complete description of the operation of the circuit can be made. The total current of 3 amps leaves the negative terminal of the battery and flows through the 8-ohm resistor (R_1). In so doing, a voltage drop of 24 volts occurs across resistor R_1. At point A, this 3-ampere current divides into two currents. Of the total current, 1.8 amps flows through the 20-ohm resistor. The remaining current of 1.2 amps flows from point A, down through the 30-ohm resistor to point B. This current produces a voltage drop of 36 volts across the 30-ohm resistor. (Notice that the voltage drops across the 20- and 30-ohm resistors are the same.) The two branch currents of 1.8 and 1.2 amps combine at junction B and the total current of 3 amps flows back to the source. The action of the circuit has been completely described with the exception of power consumed, which could be described using the values previously computed.

It should be pointed out that the combination circuit is not difficult to solve. The key to its solution lies in knowing the order in which the steps of the solution must be accomplished.

Practice Circuit Problem

Figure 3-55 is a typical combination circuit. To make sure you understand the techniques of solving for the unknown quantities, solve for E_{R1}.

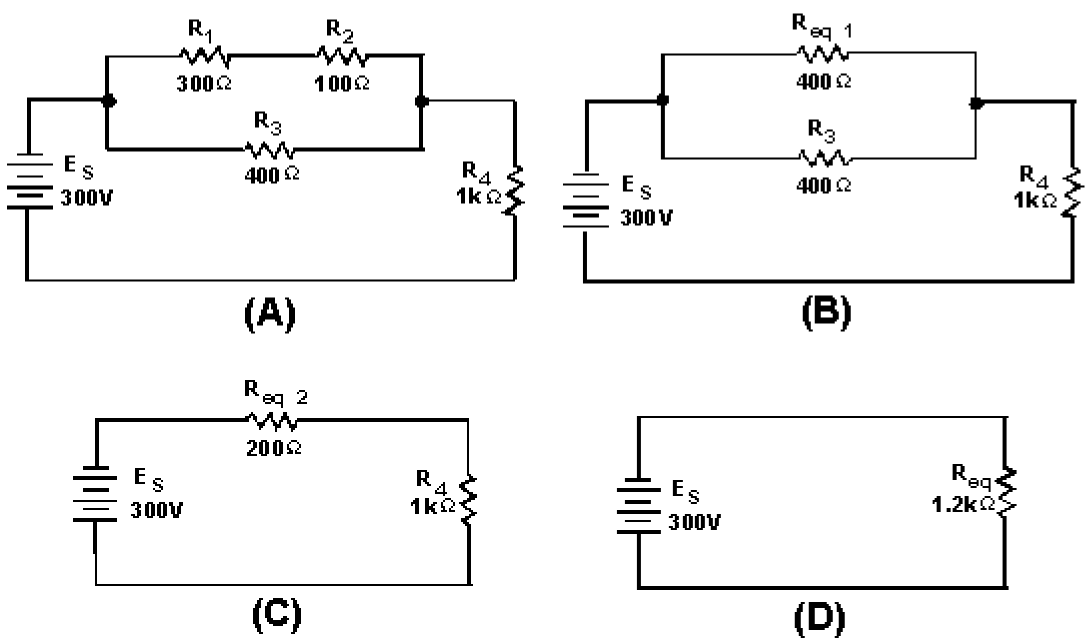


Figure 3-55.—Combination practice circuit.

It is not necessary to solve for all the values in the circuit to compute the voltage drop across resistor R_1 (E_{R1}). First look at the circuit and determine that the values given do not provide enough information to solve for E_{R1} directly.

If the current through R_1 (I_{R1}) is known, then E_{R1} can be computed by applying the formula:

$$E_{R1} = R_1 \times I_{R1}$$

The following steps will be used to solve the problem.

1. The total resistance (R_T) is calculated by the use of equivalent resistance.

Given:

$$R_1 = 300\Omega$$
$$R_2 = 100\Omega$$

Solution:

$$R_{eq1} = R_1 + R_2$$
$$R_{eq1} = 300\Omega + 100\Omega$$
$$R_{eq1} = 400\Omega$$

Redraw the circuit as shown in figure 3-55(B).

Given:

$$R_{eq1} = 400\Omega$$
$$R_3 = 400\Omega$$

Solution:

$$R_{eq2} = \frac{R}{N} \quad \text{(Equal resistors in parallel)}$$
$$R_{eq2} = \frac{400\Omega}{2}$$
$$R_{eq2} = 200\Omega$$

Solution:

$$R_{eq2} = \frac{R}{N}$$
$$R_{eq2} = \frac{400\Omega}{2}$$
$$R_{eq2} = 200\Omega$$

Redraw the circuit as shown in figure 3-55(C).

Given:

$$R_{eq2} = 200\Omega$$
$$R_4 = 1k\Omega$$

Solution:

$$R_{eq} = R_{eq2} + R_4$$
$$R_{eq} = 200\Omega + 1k\Omega$$
$$R_{eq} = 1.2k\Omega$$

2. The total current (I_T) is now computed.

Given:

$$E_S = 300V$$
$$R_{eq} = 1.2k\Omega$$

Solution:

$$I_T = \frac{E_S}{R_{eq}}$$

$$I_T = \frac{300V}{1.2k\Omega}$$

$$I_T = 250mA$$

3. Solve for the voltage dropped across R_{eq2}. This represents the voltage dropped across the network R_1, R_2, and R_3 in the original circuit.

Given:

$$R_{eq} = 200\Omega$$
$$I_T = 250mA$$

Solution:

$$E_{Req2} = R_{eq2} \times I_T$$
$$E_{Req2} = 200\Omega \times 250mA$$
$$E_{Req2} = 50V$$

4. Solve for the current through R_{eq1}. (R_{eq1} represents the network R_1 and R_2 in the original circuit.) Since the voltage across each branch of a parallel circuit is equal to the voltage across the equivalent resistor representing the circuit:

Given:

$$E_{Req2} = E_{Req1}$$
$$E_{Req1} = 50V$$
$$R_{eq1} = 400\Omega$$

Solution:

$$I_{Req1} = \frac{E_{Req1}}{R_{eq1}}$$
$$I_{Req1} = \frac{50V}{400\Omega}$$
$$I_{Req1} = 125mA$$

5. Solve for the voltage dropped across R_1 (the quantity you were asked to find). Since R_{eq1} represents the series network of R_1 and R_2 and total current flows through each resistor in a series circuit, I_{R1} must equal I_{Req1}.

Given:

$$I_{R1} = 125mA$$
$$R_1 = 300\Omega$$

Solution:

$$E_{R1} = I_{R1} \times R_1$$
$$E_{R1} = 125mA \times 300\Omega$$
$$E_{R1} = 37.5V$$

Q42. Refer to figure 3-55(A). If the following resistors were replaced with the values indicated: R_1 = 900Ω, R_3 = lkΩ, what is the total power in the circuit? What is E_{R2}?

REDRAWING CIRCUITS FOR CLARITY

You will notice that the schematic diagrams you have been working with have shown parallel circuits drawn as neat square figures, with each branch easily identified.

In actual practice the wired circuits and more complex schematics are rarely laid out in this simple form. For this reason, it is important for you to recognize that circuits can be drawn in a variety of ways, and to learn some of the techniques for redrawing them into their simplified form. When a circuit is redrawn for clarity or to its simplest form, the following steps are used.

1. Trace the current paths in the circuit.

2. Label the junctions in the circuit.

3. Recognize points which are at the same potential.

4. Visualize a rearrangement, "stretching" or "shrinking," of connecting wires.

5. Redraw the circuit into simpler form (through stages if necessary).

To redraw any circuit, start at the source, and trace the path of current flow through the circuit. At points where the current divides, called JUNCTIONS, parallel branches begin. These junctions are key points of reference in any circuit and should be labeled as you find them. The wires in circuit schematics are assumed to have NO RESISTANCE and there is NO VOLTAGE drop along any wire. This means that any unbroken wire is at the same voltage all along its length, until it is interrupted by a resistor, battery, or some other circuit component. In redrawing a circuit, a wire can be "stretched" or "shrunk" as much as you like without changing any electrical characteristic of the circuit.

Figure 3-56(A) is a schematic of a circuit that is not drawn in the box-like fashion used in previous illustrations. To redraw this circuit, start at the voltage source and trace the path for current to the junction marked (a). At this junction the current divides into three paths. If you were to stretch the wire to show the three current paths, the circuit would appear as shown in figure 3-56(B).

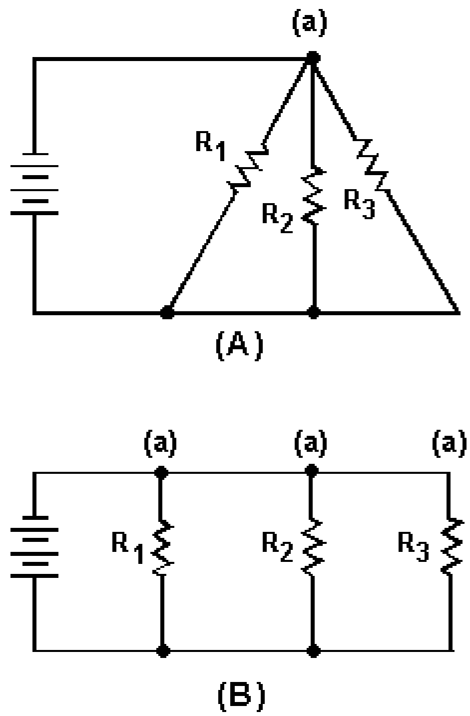


Figure 3-56.—Redrawing a simple parallel circuit.

While these circuits may appear to be different, the two drawings actually represent the same circuit. The drawing in figure 3-56(B) is the familiar box-like structure and may be easier to work with. Figure 3-57(A) is a schematic of a circuit shown in a box-like structure, but may be misleading. This circuit in reality is a series-parallel circuit that may be redrawn as shown in figure 3-57(B). The drawing in part (B) of the figure is a simpler representation of the original circuit and could be reduced to just two resistors in parallel.

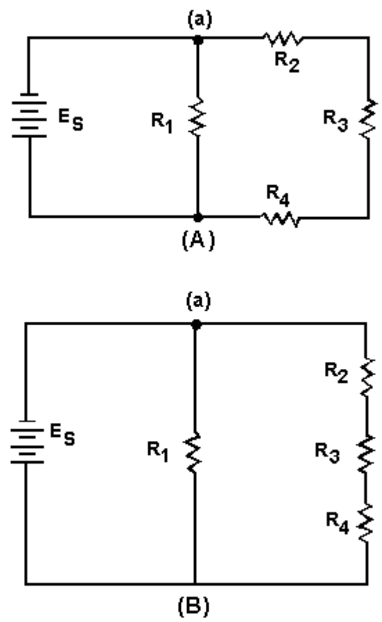


Figure 3-57.—Redrawing a simple series-parallel circuit.

Redrawing a Complex Circuit

Figure 3-58(A) shows a complex circuit that may be redrawn for clarification in the following steps.

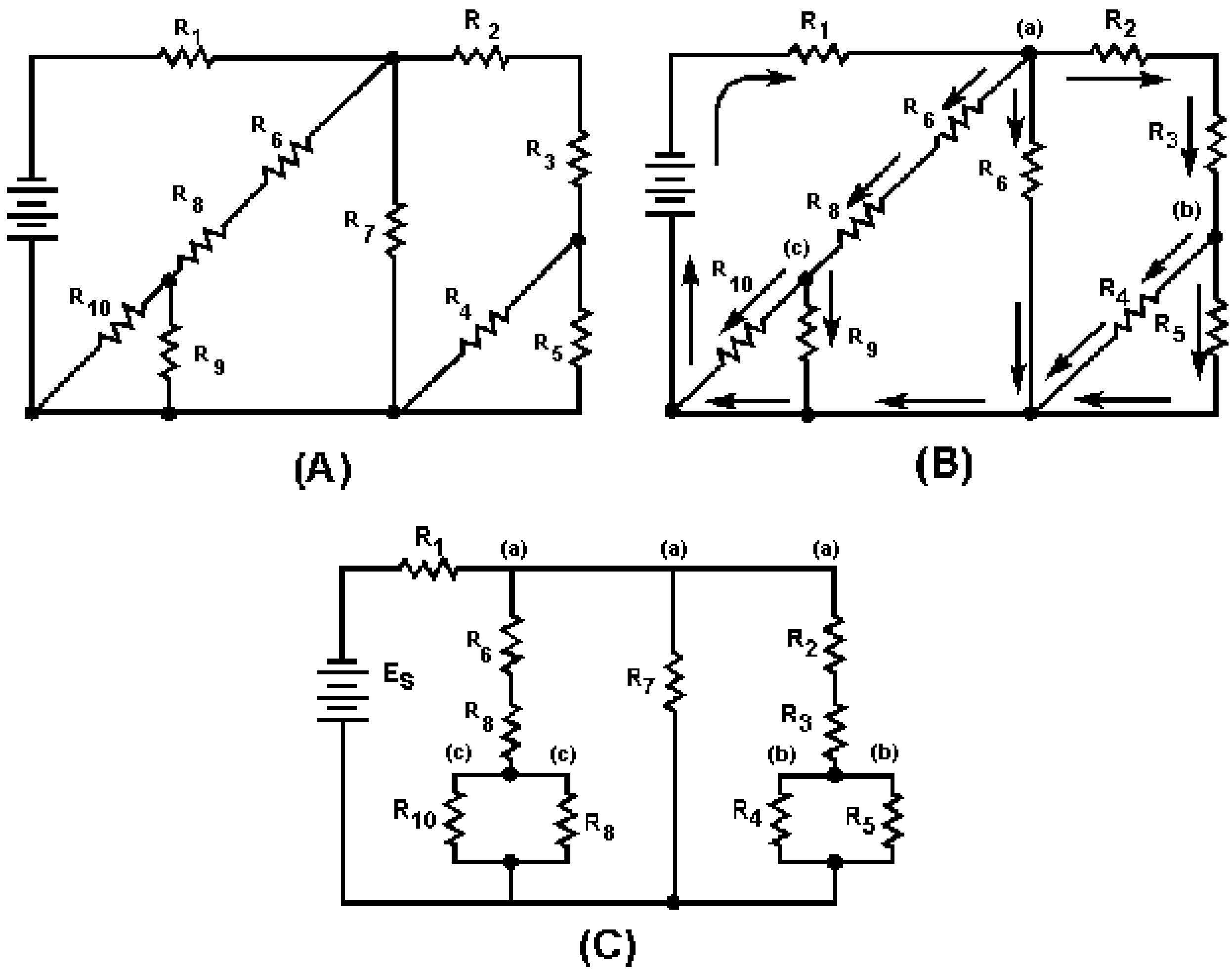


Figure 3-58.—Redrawing a complex circuit.

NOTE: As you redraw the circuit, draw it in simple box-like form. Each time you reach a junction, a new branch is created by stretching or shrinking the wires.

Start at the negative terminal of the voltage source. Current flows through R_1 to a junction and divides into three paths; label this junction (a). Follow one of the paths of current through R_2 and R_3 to a junction where the current divides into two more paths. This junction is labeled (b).

The current through one branch of this junction goes through R_5 and back to the source. (The most direct path.) Now that you have completed a path for current to the source, return to the last junction, (b). Follow current through the other branch from this junction. Current flows from junction (b) through R_4 to the source. All the paths from junction (b) have been traced. Only one path from junction (a) has been completed. You must now return to junction (a) to complete the other two paths. From junction (a) the current flows through R_7 back to the source. (There are no additional branches on this path.) Return to junction (a) to trace the third path from this junction. Current flows through R_6 and R_8 and comes to a junction. Label this junction (c). From junction (c) one path for current is through R_9 to the source. The other path for current from junction (c) is through R_{10} to the source. All the junctions in this circuit have now been labeled. The circuit and the junction can be redrawn as shown in figure 3-58(C). It is much easier to recognize the series and parallel paths in the redrawn circuit.

Q43. What is the total resistance of the circuit shown in figure 3-59? (Hint: Redraw the circuit to simplify and then use equivalent resistances to compute for R_T.)

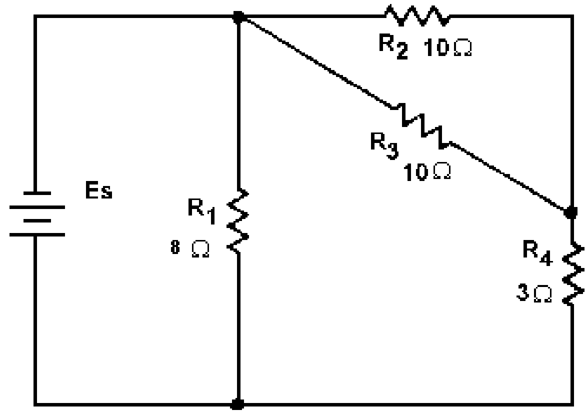


Figure 3-59.—Simplification circuit problem.

Q44. What is the total resistance of the circuit shown in figure 3-60?

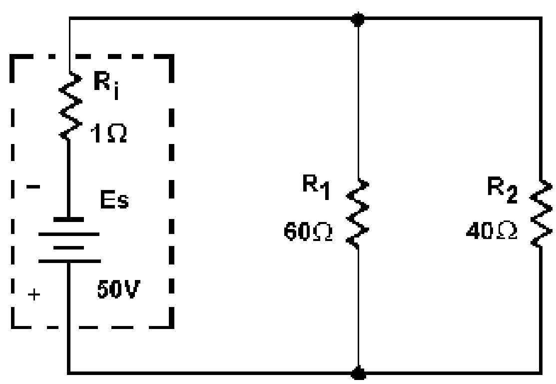


Figure 3-60.—Source resistance in a parallel circuit.

Q45. What effect does the internal resistance have on the rest of the circuit shown in figure 3-60?

EFFECTS OF OPEN AND SHORT CIRCUITS

Earlier in this chapter the terms open and short circuits were discussed. The following discussion deals with the effects on a circuit when an open or a short occurs.

The major difference between an open in a parallel circuit and an open in a series circuit is that in the parallel circuit the open would not necessarily disable the circuit. If the open condition occurs in a series portion of the circuit, there will be no current because there is no complete path for current flow. If, on the other hand, the open occurs in a parallel path, some current will still flow in the circuit. The parallel branch where the open occurs will be effectively disabled, total resistance of the circuit will INCREASE, and total current will DECREASE.

To clarify these points, figure 3-61 illustrates a series parallel circuit. First the effect of an open in the series portion of this circuit will be examined. Figure 3-61(A) shows the normal circuit, R_T = 40 ohms and I_T = 3 amps. In figure 3-61(B) an open is shown in the series portion of the circuit, there is no complete path for current and the resistance of the circuit is considered to be infinite.

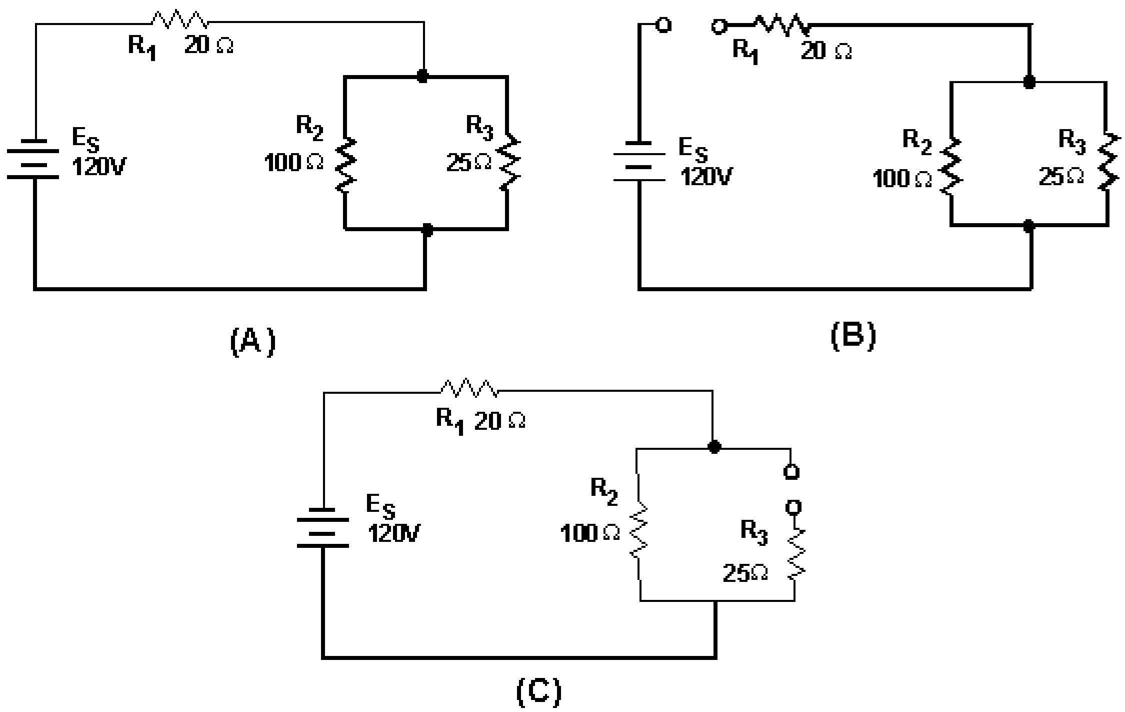


Figure 3-61.—Series-parallel circuit with opens.

In figure 3-61(C) an open is shown in the parallel branch of R_3. There is no path for current through R_3. In the circuit, current flows through R_1 and R_2 only. Since there is only one path for current flow, R_1 and R_2 are effectively in series.

Under these conditions $R_T = 120\Omega$ and I_T = 1 amp. As you can see, when an open occurs in a parallel branch, total circuit resistance increases and total circuit current decreases.

A short circuit in a parallel network has an effect similar to a short in a series circuit. In general, the short will cause an increase in current and the possibility of component damage regardless of the type of circuit involved. To illustrate this point, figure 3-62 shows a series-parallel network in which shorts are developed. In figure 3-62 (A) the normal circuit is shown. R_T = 40 ohms and I_T = 3 amps.

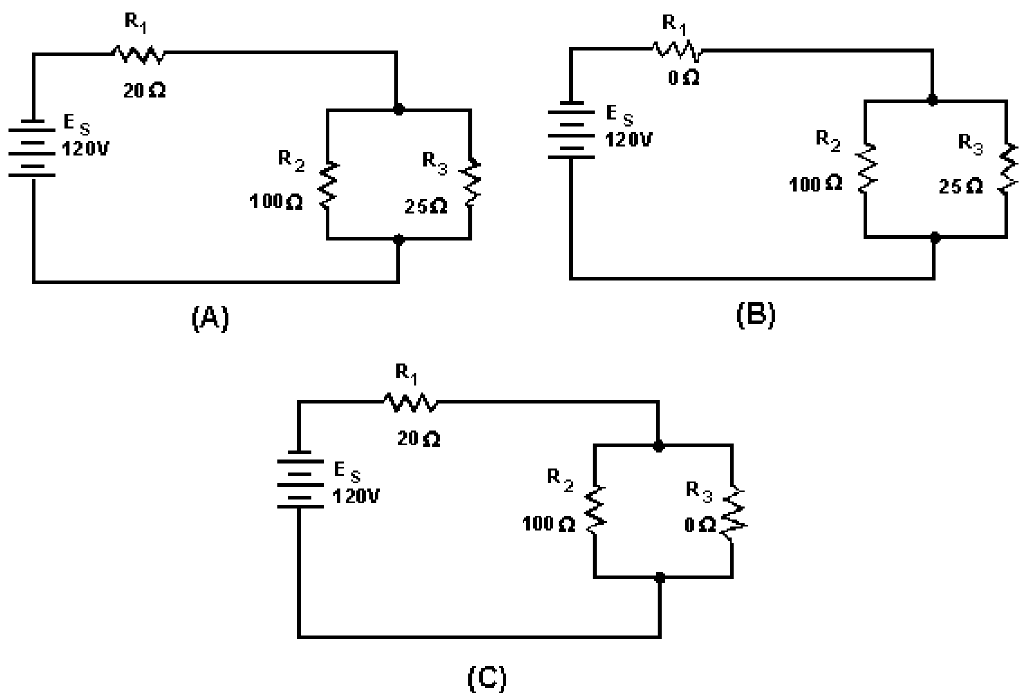


Figure 3-62.—Series-parallel circuit with shorts.

In figure 3-62 (B), R_1 has shorted. R_1 now has zero ohms of resistance. The total of the resistance of the circuit is now equal to the resistance of the parallel network of R_2 and R_3, or 20 ohms. Circuit current has increased to 6 amps. All of this current goes through the parallel network (R_2, R_3) and this increase in current would most likely damage the components.

In figure 3-62 (C), R_3 has shorted. With R_3 shorted there is a short circuit in parallel with R_2. The short circuit routes the current around R_2, effectively removing R_2 from the circuit. Total circuit resistance is now equal to the resistance of R_1, or 20 ohms.

As you know, R_2 and R_3 form a parallel network. Resistance of the network can be calculated as follows:

Given:

$$R_2 = 100\Omega$$
$$R_3 = 0\Omega$$

Solution:

$$R_{eq} = \frac{R_2 \times R_3}{R_2 + R_3}$$

$$R_{eq} = \frac{100\Omega \times 0\Omega}{100\Omega + 0\Omega}$$

$$R_{eq} = 0\Omega$$

The total circuit current with R_3 shorted is 6 amps. All of this current flows through R_1 and would most likely damage R_1. Notice that even though only one portion of the parallel network was shorted, the entire paralleled network was disabled.

Opens and shorts alike, if occurring in a circuit, result in an overall change in the equivalent resistance. This can cause undesirable effects in other parts of the circuit due to the corresponding change in the total current flow. A short usually causes components to fail in a circuit which is not properly fused or otherwise protected. The failure may take the form of a burned-out resistor, damaged source, or a fire in the circuit components and wiring.

Fuses and other circuit protection devices are installed in equipment circuits to prevent damage caused by increases in current. These circuit protection devices are designed to open if current increases to a predetermined value. Circuit protection devices are connected in series with the circuit or portion of the circuit that the device is protecting. When the circuit protection device opens, current flow ceases in the circuit.

A more thorough explanation of fuses and other circuit protection devices is presented in Module 3, *Introduction to Circuit Protection, Control, and Measurement*.

Q46. What is the effect on total resistance and total current in a circuit if an open occurs in (a) a parallel branch, and (b) in a series portion?

Q47. What is the effect on total resistance and total current in a circuit if a short occurs in (a) a parallel branch, and (b) in a series portion?

Q48. If one branch of a parallel network is shorted, what portion of circuit current flows through the remaining branches?

VOLTAGE DIVIDERS

Most electrical and electronics equipment use voltages of various levels throughout their circuitry.

One circuit may require a 90-volt supply, another a 150-volt supply, and still another a 180-volt supply. These voltage requirements could be supplied by three individual power sources. This method is expensive and requires a considerable amount of room. The most common method of supplying these voltages is to use a single voltage source and a VOLTAGE DIVIDER. Before voltage dividers are explained, a review of what was discussed earlier concerning voltage references may be of help.

As you know, some circuits are designed to supply both positive and negative voltages. Perhaps now you wonder if a negative voltage has any less potential than a positive voltage. The answer is that 100 volts is 100 volts. Whether it is negative or positive does not affect the feeling you get when you are shocked.

Voltage polarities are considered as being positive or negative in respect to a reference point, usually ground. Figure 3-63 will help to illustrate this point.

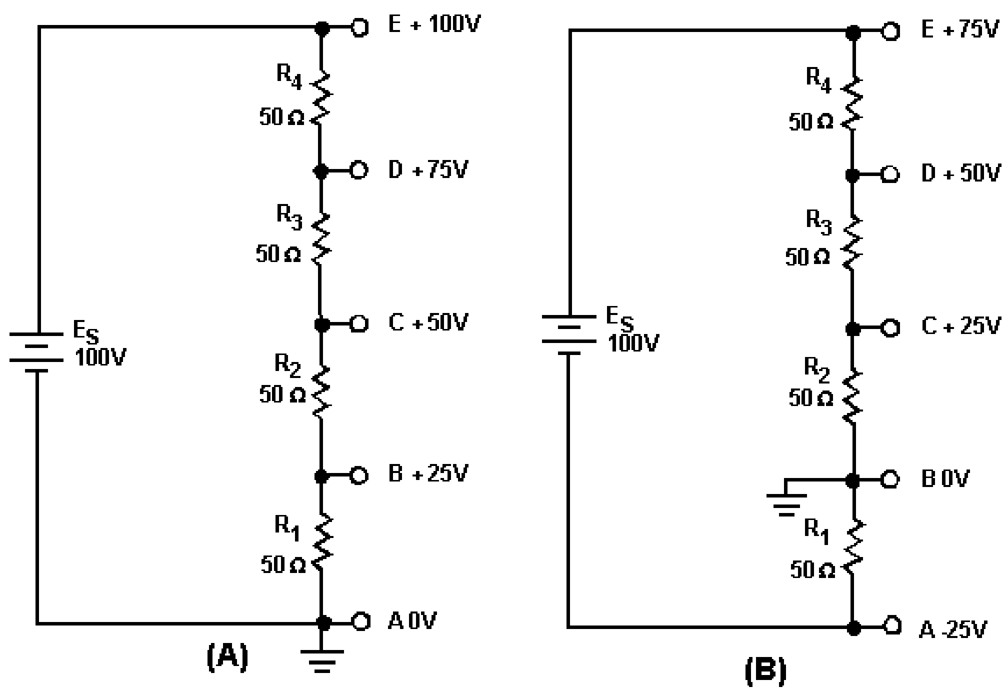


Figure 3-63.—Voltage polarities.

Figure 3-63(A) shows a series circuit with a voltage source of 100 volts and four 50-ohm resistors connected in series. The ground, or reference point, is connected to one end of resistor R_1. The current in this circuit determined by Ohm's law is .5 amp. Each resistor develops (drops) 25 volts. The five tap-off points indicated in the schematic are points at which the voltage can be measured. As indicated on the schematic, the voltage measured at each of the points from point A to point E starts at zero volts and becomes <u>more positive</u> in 25 volt steps to a value of positive 100 volts.

In figure 3-63(B), the ground, or reference point has been moved to point B. The current in the circuit is still .5 amp and each resistor still develops 25 volts. The total voltage developed in the circuit remains at 100 volts, but because the <u>reference point</u> has been changed, the voltage at point A is <u>negative</u> 25 volts. Point E, which was at positive 100 volts in figure 3-63(A), now has a voltage of positive 75 volts. As you can see the voltage at any point in the circuit is dependent on three factors; the current through the resistor, the ohmic value of the resistor, <u>and the reference point in the circuit.</u>

A typical voltage divider consists of two or more resistors connected in series across a source voltage (E_s). The source voltage must be as high or higher than any voltage developed by the voltage divider. As the source voltage is dropped in successive steps through the series resistors, any desired portion of the source voltage may be "tapped off" to supply individual voltage requirements. The values of the series resistors used in the voltage divider are determined by the voltage and current requirements of the loads.

Figure 3-64 is used to illustrate the development of a simple voltage divider. The requirement for this voltage divider is to provide a voltage of 25 volts and a current of 910 milliamps to the load from a source voltage of 100 volts. Figure 3-64(A) provides a circuit in which 25 volts is available at point B. If the load was connected between point B and ground, you might think that the load would be supplied with 25 volts. This is not true since the load connected between point B and ground forms a parallel network of the load and resistor R_1. (Remember that the value of resistance of a parallel network is always less than the value of the smallest resistor in the network.)

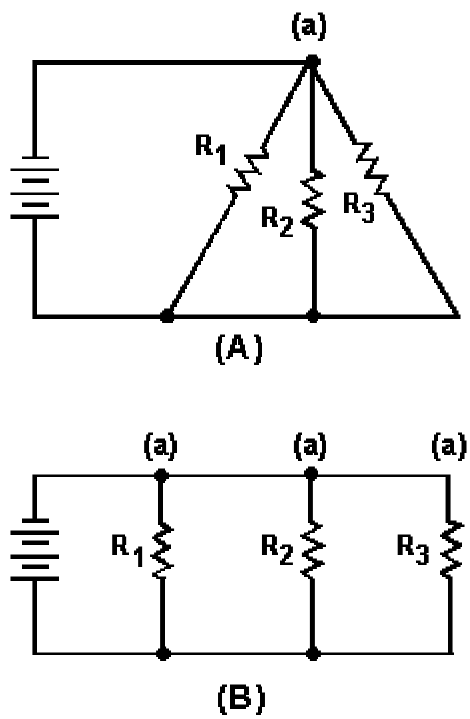


Figure 3-64.—Simple voltage divider.

Since the resistance of the network would now be less than 25 ohms, the voltage at point B would be less than 25 volts. This would not satisfy the requirement of the load.

To determine the size of resistor used in the voltage divider, a rule-of-thumb is used. The current in the divider resistor should equal approximately 10 percent of the load current. This current, which does not flow through any of the load devices, is called bleeder current.

Given this information, the voltage divider can be designed using the following steps.

1. Determine the load requirement and the available voltage source.

$$E_S = 100V$$
$$E_{load} = 25V$$
$$I_{load} = 910mA$$

2. Select bleeder current by applying the 10% rule-of-thumb.

$$I_{R1} = 10\% \times I_{load}$$
$$I_{R1} = .1 \times 910mA$$
$$I_{R1} = 91mA$$

3. Calculate bleeder resistance.

$$R_1 = \frac{E_{R1}}{I_{R1}}$$

$$R_1 = \frac{25V}{91mA}$$

$$R1 = 274.73\Omega$$

The value of R_1 may be rounded off to 275 ohms:

$$R_1 = 275\Omega$$

4. Calculate the total current (load plus bleeder).

$$I_T = I_{load} + I_{R1}$$
$$I_T = 910mA + 91mA$$
$$I_T = 1A \text{ (rounded off)}$$

5. Calculate the resistance of the other divider resistor(s).

$$E_{R2} = E_S - E_{R1}$$
$$E_{R2} = 100V - 25V$$
$$E_{R2} = 75V$$
$$R_2 = \frac{E_{R2}}{I_T}$$
$$R_2 = \frac{75V}{1A}$$
$$R_2 = 75\Omega$$

The voltage divider circuit can now be drawn as shown in figure 3-64(B).

Q49. What information must be known to determine the component values for a voltage divider?

Q50. If a voltage divider is required for a load that will use 450 mA of current, what should be the value of bleeder current?

Q51. If the load in question 50 requires a voltage of +90 V, what should be the value of the bleeder resistor?

Q52. If the source voltage for the voltage divider in question 50 supplies 150 volts, what is the total current through the voltage divider?

MULTIPLE-LOAD VOLTAGE DIVIDERS

A multiple-load voltage divider is shown in figure 3-65. An important point that was not emphasized before is that when using the 10% rule-of-thumb to calculate the bleeder current, you must take 10% of the total load current.

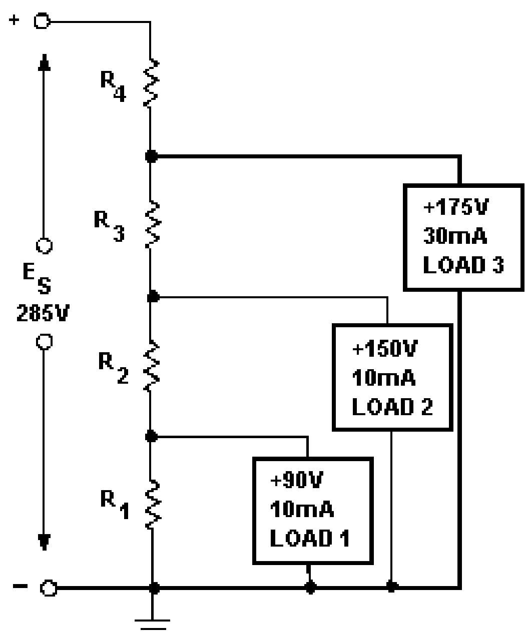


Figure 3-65.—Multiple-load voltage divider.

Given the information shown in figure 3-65, you can calculate the values for the resistors needed in the voltage-divider circuits. The same steps will be followed as in the previous voltage divider problem.

Given:

$$\text{Load 1: } E = 90V \quad I = 10mA$$

$$\text{Load 2: } E = 150V \quad I = 10mA$$

$$\text{Load 3: } E = 175V \quad I = 30mA$$

$$E_S = 285V$$

The bleeder current should be 10% of the total load current.

Solution:

$$I_{R1} = 10\% \times I(\text{load total})$$
$$I_{R1} = 10\% \times (10mA + 10mA + 30mA)$$
$$I_{R1} = 5mA$$

Since the voltage across R_1 (E_{R1}) is equal to the voltage requirement for load 1, Ohm's law can be used to calculate the value for R_1.

Solution:

$$R_1 = \frac{E_{R1}}{I_{R1}}$$

$$R_1 = \frac{90V}{5mA}$$

$$R_1 = 18k\Omega$$

The current through R_2 (I_{R2}) is equal to the current through R_1 plus the current through load 1.

Solution:

$$I_{R2} = I_{R1} + I_{load1}$$
$$I_{R2} = 5mA + 10mA$$
$$I_{R2} = 15mA$$

The voltage across R_2 (E_{R2}) is equal to the difference between the voltage requirements of load 1 and load 2.

$$E_{R2} = E_{load2} - E_{load1}$$
$$E_{R2} = 150V - 90V$$
$$E_{R2} = 60V$$

Ohm's law can now be used to solve for the value of R_2.

Solution:

$$R_2 = \frac{E_{R2}}{I_{R2}}$$
$$R_2 = \frac{60V}{15mA}$$
$$R_2 = 4k\Omega$$

The current through R_3 (I_{R3}) is equal to the current through R_2 plus the current through load 2.

$$I_{R3} = I_{R2} + I_{load2}$$
$$I_{R3} = 15mA + 10mA$$
$$I_{R3} = 25mA$$

The voltage across R_3 (E_{R3}) equals the difference between the voltage requirement of load 3 and load 2.

$$E_{R3} = E_{load3} - E_{load2}$$
$$E_{R3} = 175V - 150V$$
$$E_{R3} = 25V$$

Ohm's law can now be used to solve for the value of R_3.

Solution:

$$R_3 = \frac{E_{R3}}{I_{R3}}$$
$$R_3 = \frac{25V}{25mA}$$
$$R_3 = 1k\Omega$$

The current through R_4 (I_{R4}) is equal to the current through R_3 plus the current through load 3. I_{R4} is equal to total circuit current (I_T).

$$I_{R4} = I_{R3} + I_{load3}$$
$$I_{R4} = 25mA + 30mA$$
$$I_{R4} = 55mA$$

The voltage across R_4 (E_{R4}) equals the difference between the source voltage and the voltage requirement of load 3.

$$E_{R4} = E_S - E_{load3}$$
$$E_{R4} = 285V - 175V$$
$$E_{R4} = 110V$$

Ohm's law can now be used to solve for the value of R_4.

Solution:

$$R_4 = \frac{E_{R4}}{I_{R4}}$$
$$R_4 = \frac{110V}{55mA}$$
$$R_4 = 2k\Omega$$

With the calculations just explained, the values of the resistors used in the voltage divider are as follows:

$$R_1 = 18k\Omega$$
$$R_2 = 4k\Omega$$
$$R_3 = 1k\Omega$$
$$R_4 = 2k\Omega$$

POWER IN THE VOLTAGE DIVIDER

Power in the voltage divider is an extremely important quantity. The power dissipated by the resistors in the voltage divider should be calculated to determine the power handling requirements of the resistors. Total power of the circuit is needed to determine the power requirement of the source.

The power for the circuit shown in figure 3-65 is calculated as follows:

Given:

$$E_{R1} = 90V$$
$$E_{R1} = 5mA$$

Solution:

$$P_{R1} = E_{R3} \times I_{R1}$$
$$P_{R1} = 90V \times 5mA$$
$$P_{R1} = .45W$$

The power in each resistor is calculated just as for R_1. When the calculations are performed, the following results are obtained:

$$P_{R2} = .9W$$
$$P_{R3} = .625W$$
$$P_{R4} = 6.05W$$

To calculate the power for load 1:

Given:

$$E_{load1} = 90V$$
$$I_{load1} = 10mA$$

Solution:

$$P_{load1} = E_{load1} \times I_{load1}$$
$$P_{load1} = 90V \times 10mA$$
$$P_{load1} = .9W$$

The power in each load is calculated just as for load 1. When the calculations are performed, the following results are obtained.

$$P_{load2} = 1.5W$$
$$P_{load3} = 5.25W$$

Total power is calculated by summing the power consumed by the loads and the power dissipated by the divider resistors. The total power in the circuit is 15.675 watts.

The power used by the loads and divider resistors is supplied by the source. This applies to all electrical circuits; power for all components is supplied by the source.

Since power is the product of voltage and current, the power supplied by the source is equal to the source voltage multiplied by the total circuit current (E_s x I_T).

In the circuit of figure 3-65, the total power can be calculated by:

Given:

$$E_S = 285V$$
$$I_T = 55mA\ (I_{R4})$$

Solution:

$$P_T = E_S \times I_T$$
$$P_T = 285V \times 55mA$$
$$P_T = 15.675W$$

VOLTAGE DIVIDER WITH POSITIVE AND NEGATIVE VOLTAGE REQUIREMENTS

In many cases the load for a voltage divider requires both positive and negative voltages. Positive and negative voltages can be supplied from a single source voltage by connecting the ground (reference point) between two of the divider resistors. The exact point in the circuit at which the reference point is placed depends upon the voltages required by the loads.

For example, a voltage divider can be designed to provide the voltage and current to three loads from a given source voltage.

Given:

Load 1: $E = -25V$
$I = 300mA$

Load 2: $E = +50V$
$I = 50mA$

Load 3: $E = +250V$
$I = 100mA$

$E_S = 310V$

The circuit is drawn as shown in figure 3-66. Notice the placement of the ground reference point. The values for resistors R_1, R_3, and R_4 are computed exactly as was done in the last example. I_{R1} is the bleeder current and can be calculated as follows:

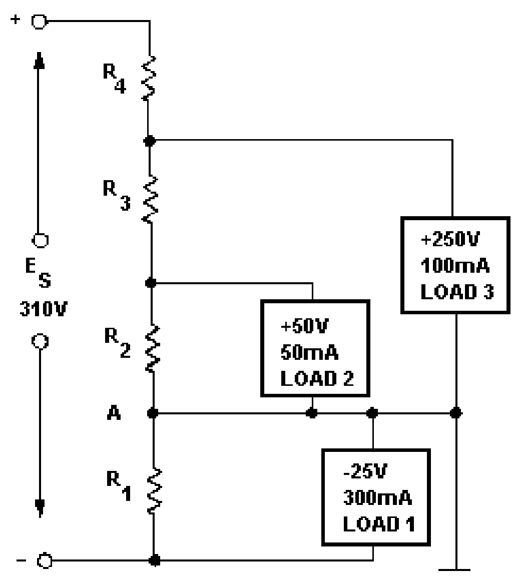


Figure 3-66.—Voltage divider providing both positive and negative voltages.

Solution:

$$I_{R1} = 10\% \times I(\text{load total})$$
$$I_{R1} = 10\% \times (300mA)$$
$$I_{R1} = 30mA$$

Calculate the value of R_1.

Solution:

$$R_1 = \frac{E_{R1}}{I_{R1}}$$

$$R_1 = \frac{25V}{45mA}$$

$$R_1 = 556\Omega$$

Calculate the current through R_2 using Kirchhoff's current law.

At point A:

$$I_{R1} + I_{load1} + I_{R2} + I_{load2} + I_{load3} = 0$$
$$45mA + 300mA + I_{R2} - 50mA - 100mA = 0$$
$$345mA + I_{R2} - 150mA = 0$$
$$195mA + I_{R2} = 0$$
$$I_{R2} = -195mA$$

(or 195mA leaving point A)

Since E_{R2} = E load 2, you can calculate the value of R_2.

Solution:

$$R_2 = \frac{E_{R2}}{I_{R2}}$$

$$R_2 = \frac{50V}{195mA}$$

$$R_2 = 256\Omega$$

Calculate the current through R_3.

$$I_{R3} = I_{R2} + I_{load2}$$
$$I_{R3} = 195mA + 50mA$$
$$I_{R3} = 245mA$$

The voltage across R_3 (E_{R3}) equals the difference between the voltage requirements of loads 3 and 2.

Solution:

$$E_{R3} = E_{load3} - E_{load2}$$
$$E_{R3} = 250V - 50V$$
$$E_{R3} = 200V$$

Calculate the value of R_3.

Solution:

$$R_3 = \frac{E_{R3}}{I_{R3}}$$

$$R_3 = \frac{200V}{245mA}$$

$$R_3 = 816\Omega$$

Calculate the current through R_4.

$$I_{R4} = I_{R3} + I_{load3}$$
$$I_{R4} = 245mA + 100mA$$
$$I_{R4} = 345mA$$

The voltage across E_{R4} equals the source voltage (E_s) minus the voltage requirement of load 3 and the voltage requirement of load 1. Remember Kirchhoff's voltage law which states that the sum of the voltage drops and emfs around any closed loop is equal to zero.

Solution:

$$E_{R4} = E_S - E_{load3} - E_{load1}$$
$$E_{R4} = 310V - 250V - 25v$$
$$E_{R4} = 35V$$

Calculate the value of R_4.

Solution:

$$R_4 = \frac{E_{R4}}{I_{R4}}$$

$$R_4 = \frac{35V}{345mA}$$

$$R_4 = 101.4\Omega$$

With the calculations just explained, the values of the resistors used in the voltage /divider are as follows:

$$R_1 = 556\Omega$$
$$R_2 = 256\Omega$$
$$R_3 = 816\Omega$$
$$R_4 = 101\Omega$$

From the information just calculated, any other circuit quantity, such as power, total current, or resistance of the load, could be calculated.

PRACTICAL APPLICATION OF VOLTAGE DIVIDERS

In actual practice the computed value of the bleeder resistor does not always come out to an even value. Since the rule-of-thumb for bleeder current is only an estimated value, the bleeder resistor can be of a value close to the computed value. (If the computed value of the resistance were 510 ohms, a 500-ohm resistor could be used.) Once the actual value of the bleeder resistor is selected, the bleeder current must be recomputed. The voltage developed by the bleeder resistor must be equal to the voltage requirement of the load in parallel with the bleeder resistor.

The value of the remaining resistors in the voltage divider is computed from the current through the remaining resistors and the voltage across them. These values must be used to provide the required voltage and current to the loads.

If the computed values for the divider resistors are not even values; series, parallel, or series-parallel networks can be used to provide the required resistance.

Example: A voltage divider is required to supply two loads from a 190.5 volts source. Load 1 requires +45 volts and 210 milliamps; load 2 requires +165 volts and 100 milliamps.

Calculate the bleeder current using the rule-of-thumb.

Given:

$$I_{load1} = 210mA$$
$$I_{load2} = 100mA$$

Solution:

$$I_{R1} = 10\% \times (210mA + 100mA)$$
$$I_{R1} = 31mA$$

Calculate the ohmic value of the bleeder resistor.

Given:

$$E_{R1} = 45V \quad (E_{load1})$$
$$I_{R1} = 31mA$$

Solution:

$$R_1 = \frac{E_{R1}}{I_{R1}}$$
$$R_1 = \frac{45V}{31mA}$$
$$R_1 = 1451.6\Omega$$

Since it would be difficult to find a resistor of 1451.6 ohms, a practical choice for R_1 is 1500 ohms.

Calculate the actual bleeder current using the selected value for R_1.

Given:

$$E_{R1} = 45V$$
$$I_{R1} = 1.5k\Omega$$

Solution:

$$I_{R1} = \frac{E_{R1}}{R_1}$$

$$I_{R1} = \frac{45V}{1.5k\Omega}$$

$$I_{R1} = 30mA$$

Using this value for I_{R1}, calculate the resistance needed for the next divider resistor. The current (I_{R2}) is equal to the bleeder current plus the current used by load 1.

Given:

$$I_{R1} = 30mA$$
$$I_{load1} = 210mA$$

Solution:

$$I_{R2} = I_{R1} + I_{load1}$$
$$I_{R2} = 30mA + 210mA$$
$$I_{R4} = 240mA$$

The voltage across R_2 (E_{R2}) is equal to the difference between the voltage requirements of loads 2 and 1, or 120 volts.

Calculate the value of R_2.

Given:

$$E_{R2} = 120V$$
$$I_{R2} = 240mA$$

Solution:

$$R_2 = \frac{E_{R2}}{I_{R2}}$$

$$R_2 = \frac{120V}{240mA}$$

$$R_2 = 500\Omega$$

The value of the final divider resistor is calculated with I_{R3} (I_{R2} + I load 2) equal to 340 mA and E_{R3} (E_s - E load 2) equal to 25.5V.

Given:

$$E_{R3} = 25.5V$$
$$I_{R3} = 340mA$$

Solution:

$$R_3 = \frac{E_{R3}}{I_{R3}}$$

$$R_3 = \frac{25.5V}{340mA}$$

$$R_3 = 75\Omega$$

A 75-ohm resistor may not be easily obtainable, so a network of resistors equal to 75 ohms can be used in place of R_3.

Any combination of resistor values adding up to 75 ohms could be placed in series to develop the required network. For example, if you had two 37.5-ohm resistors, you could connect them in series to get a network of 75 ohms. One 50-ohm and one 25-ohm resistor or seven 10-ohm and one 5-ohm resistor could also be used.

A parallel network could be constructed from two 150-ohm resistors or three 225-ohm resistors. Either of these parallel networks would also be a network of 75 ohms.

The network used in this example will be a series-parallel network using three 50-ohm resistors.

With the information given, you should be able to draw this voltage divider network.

Once the values for the various divider resistors have been selected, you can compute the power used by each resistor using the methods previously explained. When the power used by each resistor is known, the wattage rating required of each resistor determines the physical size and type needed for the circuit. This circuit is shown in figure 3-67.

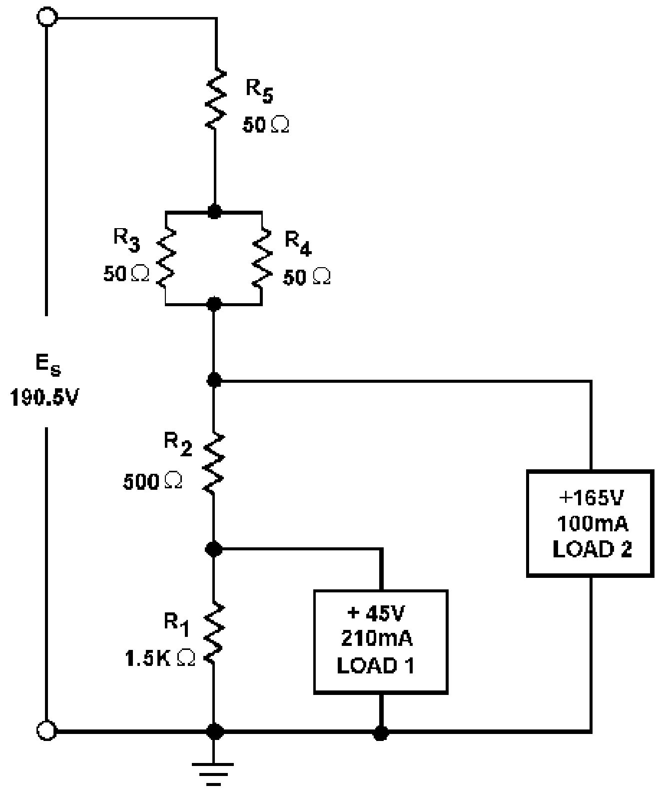


Figure 3-67.—Practical example of a voltage divider.

Q53. In figure 3-67, why is the value of R_1 calculated first?

Q54. In figure 3-67, how is (a) the current through R_2 and (b) the voltage drop across R_2 computed?

Q55. In figure 3-67, what is the power dissipated in R_1?

Q56. In figure 3-67, what is the purpose of the series-parallel network R_3, R_4, and R_5?

Q57. In figure 3-67, what should be the minimum wattage ratings of R_3 and R_5?

Q58. If the load requirement consists of both positive and negative voltages, what technique is used in the voltage divider to supply the loads from a single voltage source?

EQUIVALENT CIRCUIT TECHNIQUES

The circuit solutions that you have studied up to this point have been obtained mainly through the use of formulas derived from Ohm's law. As in many other fields of science, electricity has its share of special shortcut methods. Some of the special circuit analysis techniques are: THEVENIN'S THEOREM, which uses a process of circuit reduction to Thevenin's equivalent circuit; and NORTON'S THEOREM, which is reduction of a circuit to Norton's equivalent. Another method is called LOOP ANALYSIS. This uses Kirchhoff's voltage law to simultaneously solve problems in parallel branches of a circuit. The use of these methods should be reserved until you have become thoroughly familiar with the methods covered thus far in this chapter. You may want to explore some of the special techniques later in your career.

ELECTRICAL SAFETY

Safety precautions must always be observed by persons working around electric circuits and equipment to avoid injury from electric shock. Detailed safety precautions are contained in NAVMAT P-5l00, *Safety Precautions for Shore Activities* and OPNAVINST 5l00-19, *Navy Safety Precautions for Forces Afloat*.

The danger of shock from a 450-volt ac electrical service system is well recognized by operating personnel. This is shown by the relatively low number of reports of serious shock received from this voltage, despite its widespread use. On the other hand, a number of fatalities have been reported due to contact with low-voltage circuits. Despite a fairly widespread, but totally unfounded, popular belief to the contrary, low-voltage circuits (115 volts and below) are very dangerous and can cause death when the resistance of the body is lowered. Fundamentally, current, rather than voltage, is the measure of shock intensity. The passage of even a very small current through a vital part of the human body can cause DEATH. The voltage necessary to produce the fatal current is dependent upon the resistance of the body, contact conditions, the path through the body, etc. For example, when a 60-hertz alternating current, is passed through a human body from hand to hand or from hand to foot, and the current is gradually increased, it will cause the following effects: At about 1 milliampere (0.001 ampere), the shock can be felt; at about 10 milliamperes (0.01 ampere), the shock is of sufficient intensity to prevent voluntary control of the muscles; and at about 100 milliamperes (0.1 ampere) the shock is fatal if it lasts for 1 second or more. The above figures are the results of numerous investigations and are approximate because individuals differ in their resistance to electrical shock. It is most important to recognize that the resistance of the human body cannot be relied upon to prevent a fatal shock from 115 volts or less—FATALITIES FROM VOLTAGES AS LOW AS 30 VOLTS HAVE BEEN RECORDED. Tests have shown that body resistance under unfavorable conditions may be as low as 300 ohms, and possibly as low as 100 ohms from temple to temple if the skin is broken.

Conditions aboard ship add to the chance of receiving an electrical shock. Aboard ship the body is likely to be in contact with the metal structure of the ship and the body resistance may be low because of perspiration or damp clothing. Extra care and awareness of electrical hazards aboard ship are needed.

Short circuits can be caused by accidentally placing or dropping a metal tool, rule, flashlight case, or other conducting article across an energized line. The arc and fire which result, even on relatively low-voltage circuits, may cause extensive damage to equipment and serious injury to personnel.

Since ship service power distribution systems are designed to be ungrounded, many persons believe it is safe to touch one conductor, since no electrical current would flow. This is not true, since the distribution system is not totally isolated from the hull of the ship. If one conductor of an ungrounded electrical system is touched while the body is in contact with the hull of the ship or other metal equipment enclosure, a fatal electric current may pass through the body. ALL LIVE ELECTRIC CIRCUITS SHALL BE TREATED AS POTENTIAL HAZARDS AT ALL TIMES.

DANGER SIGNALS

Personnel should constantly be on the alert for any signs which might indicate a malfunction of electric equipment. Besides the more obvious visual signs, the reaction of other senses, such as hearing, smell, and touch, should also make you aware of possible electrical malfunctions. Examples of signs which you must be alert for are: fire, smoke, sparks, arcing, or an unusual sound from an electric motor.

Frayed and damaged cords or plugs; receptacles, plugs, and cords which feel warm to the touch; slight shocks felt when handling electrical equipment; unusually hot running electric motors and other electrical equipment; an odor of burning or overheated insulation; electrical equipment which either fails to operate or operates irregularly; and electrical equipment which produces excessive vibrations are also indications of malfunctions. When any of the above signs are noted, they are to be reported immediately to a qualified technician. DO NOT DELAY. Do not operate faulty equipment. Above all, do not attempt to make any repairs yourself if you are not qualified to do so. Stand clear of any suspected hazard and instruct others to do likewise.

- Warning Signs—They have been placed for your protection. To disregard them is to invite personal injury as well as possible damage to equipment. Switches and receptacles with a temporary warning tag, indicating work is being performed, are not to be touched.

- Working Near Electrical Equipment—When work must be performed in the immediate vicinity of electrical equipment, check with the technician responsible for the maintenance of the equipment so you can avoid any potential hazards of which you may not be immediately aware.

- Authorized Personnel Only—Because of the danger of fire, damage to equipment, and injury to personnel, all repair and maintenance work on electrical equipment shall be done only by authorized persons. Keep your hands off of all equipment which you have not been specifically authorized to handle. Particularly stay clear of electrical equipment opened for inspection, testing, or servicing.

- Circuit Breakers and Fuses—Covers for all fuse boxes, junction boxes, switch boxes, and wiring accessories should be kept closed. Any cover which is not closed or is missing should be reported to the technician responsible for its maintenance. Failure to do so may result in injury to personnel or damage to equipment in the event accidental contact is made with exposed live circuits.

ELECTRICAL FIRES

Carbon dioxide (CO_2) is used in fighting electrical fires. It is nonconductive and, therefore, the safest to use in terms of electrical safety. It also offers the least likelihood of damaging equipment. However, if the discharge horn of a CO_2 extinguisher is allowed to accidentally touch an energized circuit, the horn may transmit a shock to the person handling the extinguisher.

The very qualities which cause CO_2 to be a valuable extinguishing agent also make it dangerous to life. When it replaces oxygen in the air to the extent that combustion cannot be sustained, respiration also cannot be sustained. Exposure of a person to an atmosphere of high concentration of CO_2 will cause suffocation.

FIRST AID FOR ELECTRIC SHOCK

A person who has stopped breathing is not necessarily dead, but is in immediate danger. Life is dependent upon oxygen, which is breathed into the lungs and then carried by the blood to every body cell. Since body cells cannot store oxygen, and since the blood can hold only a limited amount (and that only for a short time), death will surely result from continued lack of breathing.

However, the heart may continue to beat for some time after breathing has stopped, and the blood may still be circulated to the body cells. Since the blood will, for a short time, contain a small supply of oxygen, the body cells will not die immediately. For a very few minutes, there is some chance that the person's life may be saved.

The process by which a person who has stopped breathing can be saved is called ARTIFICIAL VENTILATION (RESPIRATION).

The purpose of artificial ventilation is to force air out of the lungs and into the lungs, in rhythmic alternation, until natural breathing is reestablished. Artificial ventilation should be given only when natural breathing has stopped; it should NOT be given to any person who is breathing naturally. You should not assume that an individual who is unconscious due to electrical shock has stopped breathing. To tell if someone suffering from an electrical shock is breathing, place your hands on the person's sides, at the level of the lowest ribs. If the victim is breathing, you will usually be able to feel the movement. Remember: DO NOT GIVE ARTIFICIAL VENTILATION TO A PERSON WHO IS BREATHING NATURALLY.

Records show that seven out of ten victims of electric shock were revived when artificial respiration was started in less than 3 minutes. After 3 minutes, the chances of revival decrease rapidly.

Once it has been determined that breathing has stopped, the person nearest the victim should start the artificial ventilation without delay and send others for assistance and medical aid. The only logical, permissible delay is that required to free the victim from contact with the electricity in the quickest, safest way. This step, while it must be taken quickly, must be done with great care; otherwise, there may be two victims instead of one. In the case of portable electric tools, lights, appliances, equipment, or portable outlet extensions, this should be done by turning off the supply switch or by removing the plug from its receptacle. If the switch or receptacle cannot be quickly located, the suspected electrical device may be pulled free of the victim. Other persons arriving on the scene must be clearly warned not to touch the suspected equipment until it is deenergized. Aid should be enlisted to unplug the device as soon as possible. The injured person should be pulled free of contact with stationary equipment (such as a bus bar) if the equipment cannot be quickly deenergized, or if considerations of military operation or unit survival prevent immediate shutdown of the circuits.

This can be done quickly and safely by carefully applying the following procedures:

1. Protect yourself with dry insulating material.

2. Use a dry board, belt, clothing, or other available nonconductive material to free the victim from electrical contact. DO NOT TOUCH THE VICTIM UNTIL THE SOURCE OF ELECTRICITY HAS BEEN REMOVED.

Once the victim has been removed from the electrical source, it should be determined, if the person is breathing. If the person is not breathing, a method of artificial ventilation is used.

Sometimes victims of electrical shock suffer cardiac arrest (heart stoppage) as well as loss of breathing. Artificial ventilation alone is not enough in cases where the heart has stopped. A technique known as Cardiopulmonary Resuscitation (CPR) has been developed to provide aid to a person who has stopped breathing and suffered a cardiac arrest. Because you most likely will be working in the field of electricity, the risk of electrical shock is higher than most other Navy occupations. You should, at your earliest opportunity, learn the technique of CPR.

CPR is relatively easy to learn and is taught in courses available from the American Red Cross, some Navy Medical Departments, and in the *Standard First Aid Training Course* (NAVEDTRA 12081).

Q59. Is it considered safe for a person to touch any energized low-voltage conductor with the bare hand?

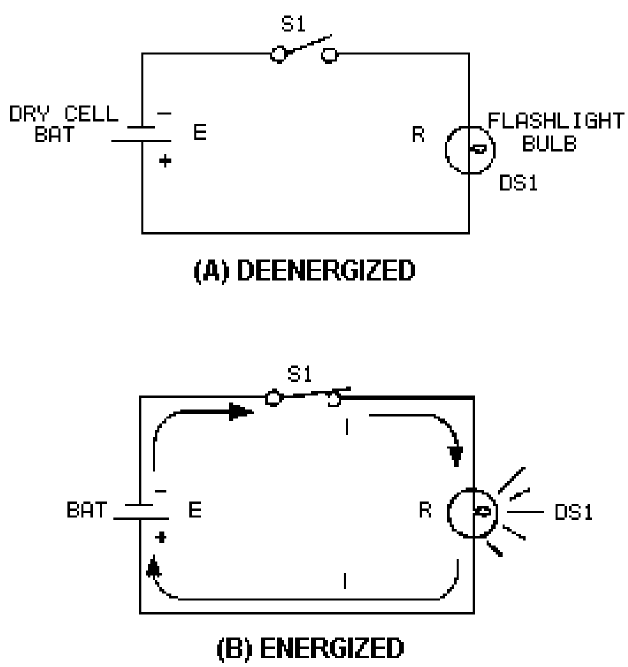
Q60. What should you do if you become aware of a possible malfunction in a piece of electrical equipment?

Q61. Who should perform CPR?

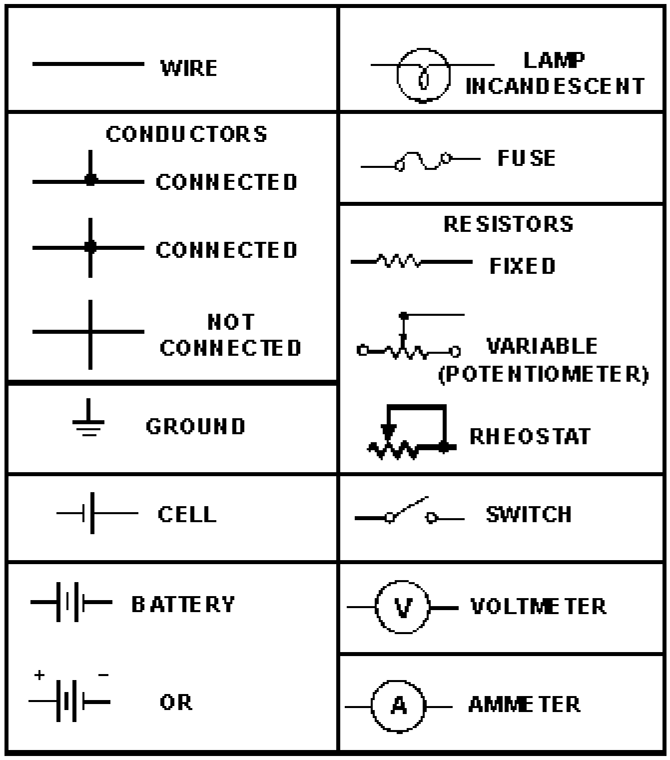
SUMMARY

With the completion of this chapter you have gained a basic understanding of dc circuits. The information you have learned will provide you with a firm foundation for continuing your study of electricity. The following is a summary of the important points in the chapter.

A BASIC ELECTRIC CIRCUIT consists of a source of electrical energy connected to a load. The load uses the energy and changes it to a useful form.



A SCHEMATIC DIAGRAM is a "picture" of a circuit, which uses symbols to represent components. The space required to depict an electrical or electronic circuit is greatly reduced by the use of a schematic.



<u>VOLTAGE (E)</u> is the electrical force or pressure operating in a circuit.

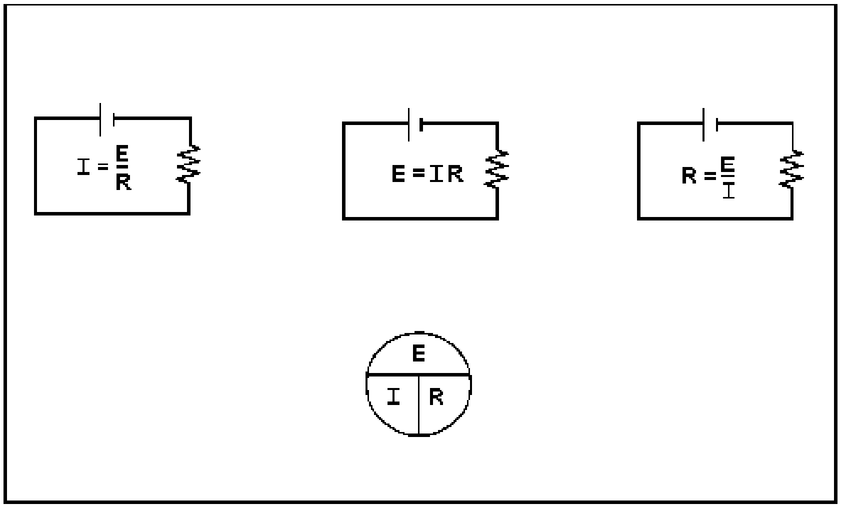
<u>AN AMPERE (A)</u> represents the current flow produced by one volt working across one ohm of resistance.

<u>RESISTANCE (R)</u> is the opposition to current. It is measured in ohms (Ω). One ohm of resistance will limit the current produced by one volt to a level of one ampere.

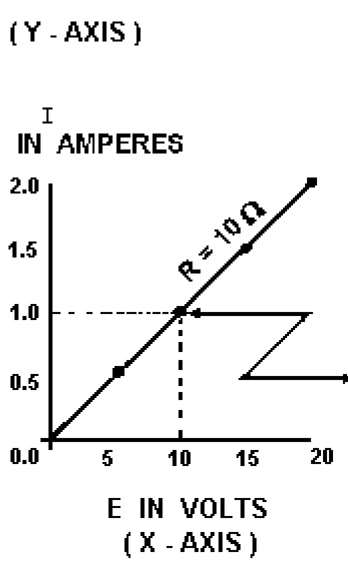
<u>THE OHM'S FORMULA</u> can be transposed to find one of the values in a circuit if the other two values are known. You can transpose the Ohm's law formula

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

mathematically, or you can use the Ohm's law figure to determine the mathematical relationship between R, E, and I.



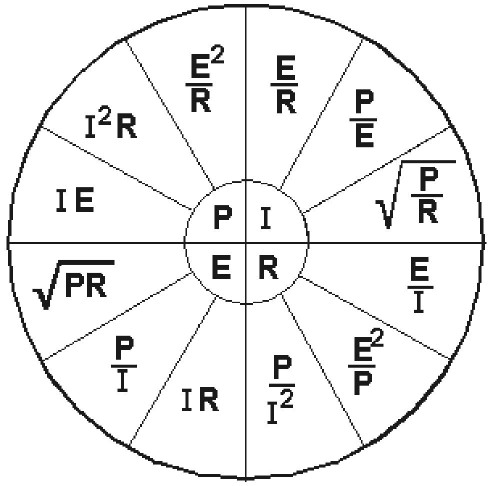
<u>GRAPHICAL ANALYSIS</u> of the relationship between R, E, and I can be studied by plotting these quantities on a graph. Such a graph is useful for observing the characteristics of an electrical device.



R = 10 Ω	
E	I
0	0.0
5	0.5
10	1.0
15	1.5
20	2.0

<u>POWER</u> is the rate of doing work per unit of time. The time required to perform a given amount of work will determine the power expended. As a formula, P = E x I, where P = power in watts, E = voltage in volts, and I = current in amperes.

<u>THE FOUR BASIC ELECTRICAL QUANTITIES</u> are P, I, E, R. Any single unknown quantity can be expressed in terms of any two of the other known quantities. The formula wheel is a simple representation of these relationships.



POWER RATING in watts indicates the rate at which a device converts electrical energy into another form of energy. The power rating of a resistor indicates the maximum power the resistor can withstand without being destroyed.

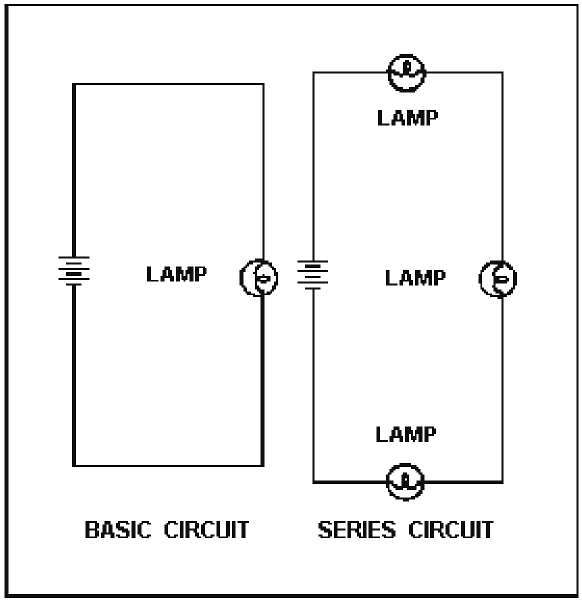
POWER USED by an electrical device is measured in watt-hours. One watt-hour is equal to one watt used continuously for one hour.

THE EFFICIENCY of an electrical device is equal to the electrical power converted into useful energy divided by the electrical power supplied to the device.

$$\text{EFF} = \frac{\text{Power converted}}{\text{Power used}}$$

HORSEPOWER is a unit of measurement often used to rate electrical motors. It is a unit of work. One horsepower is equal to 746 watts.

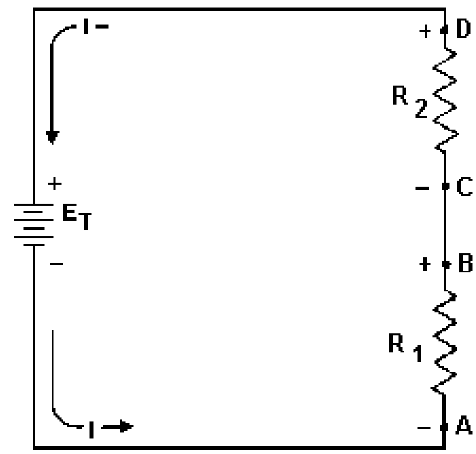
A SERIES CIRCUIT is defined as a circuit that has only one path for current flow.



RULES FOR SERIES DC CIRCUITS:

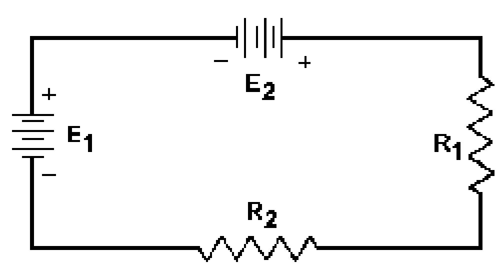
- The same current flows through each part of a series circuit.
- The total resistance of a series circuit is equal to the sum of the individual resistances.
- The total voltage across a series circuit is equal to the sum of the individual voltage drops.
- The voltage drop across a resistor in a series circuit is proportional to the ohmic value of the resistor.
- The total power in a series circuit is equal to the sum of the individual power used by each circuit component.

KIRCHHOFF'S VOLTAGE LAW states: The algebraic sum of the voltage drops in any closed path in a circuit and the electromotive forces in that path is equal to zero, or $E_a + E_b + E_c + ... E_n = 0$.

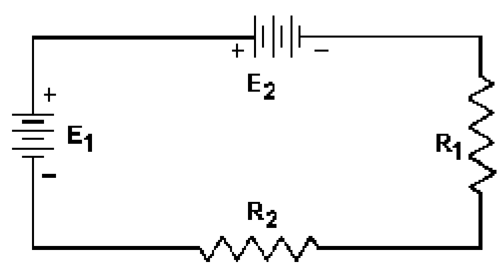


VOLTAGE POLARITIES must be used when applying Kirchhoff's voltage law. The point at which current enters a load (resistor) is considered negative with respect to the point at which current leaves the load.

SERIES AIDING VOLTAGES cause current to flow in the same direction; thus the voltages are added.



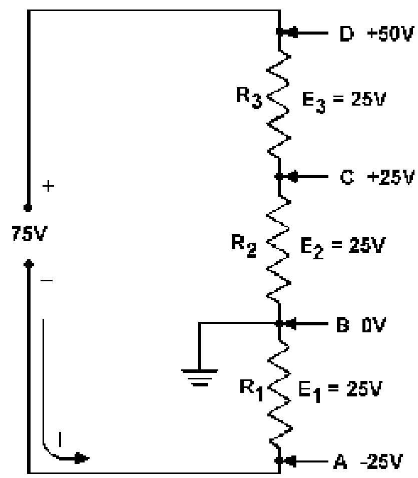
SERIES AIDING



SERIES OPPOSING

SERIES OPPOSING VOLTAGES tend to force current to flow in opposite directions; thus the equivalent voltage is the difference between the opposing voltages.

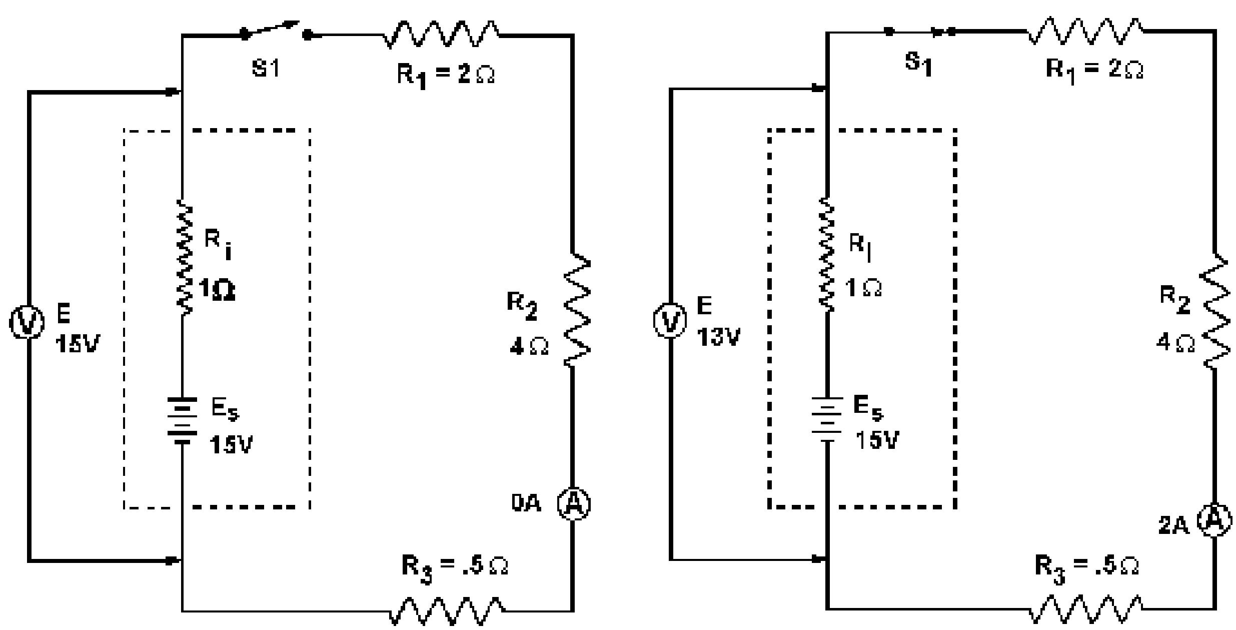
A REFERENCE POINT is a chosen point in a circuit to which all other points are compared.



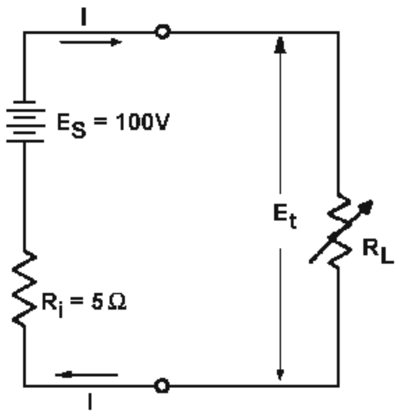
AN OPEN CIRCUIT is one in which a break exists in the complete conducting pathway.

A SHORT CIRCUIT is an accidental path of low resistance which passes an abnormally high amount of current.

INTERNAL RESISTANCE causes a drop in the terminal voltage of a source as current flows through the source. The decrease in terminal voltage is caused by the voltage drop across the internal resistance. All sources of electromotive force have some form of internal resistance.



HIGH EFFICIENCY in a circuit is achieved when the resistance of the load is high with respect to the resistance of the source.

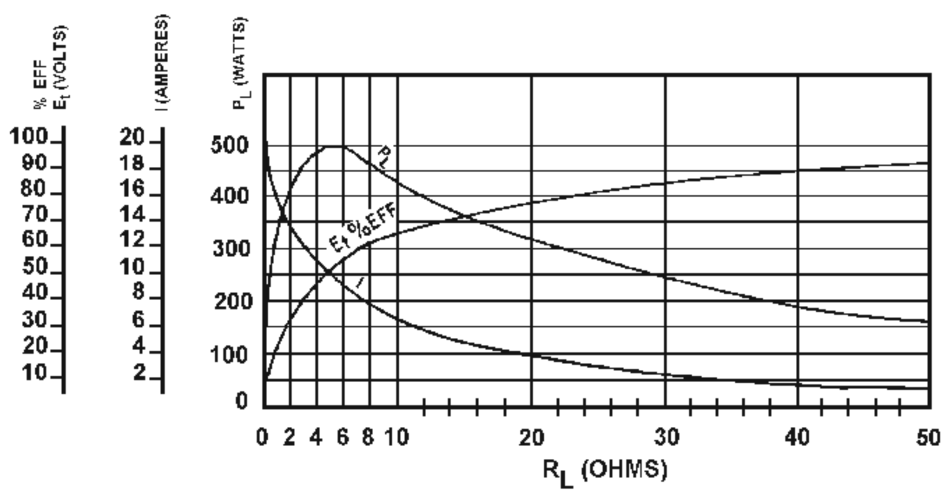


E_S = OPEN - CIRCUIT VOLTAGE OF SOURCE
R_i = INTERNAL RESISTANCE OF SOURCE
E_t = TERMINAL VOLTAGE
R_L = RESISTANCE OF LOAD
P_L = POWER USED IN LOAD
I = CURRENT FROM SOURCE
% EFF. = PERCENTAGE OF EFFICIENCY

(A)
CIRCUIT AND SYMBOL DESIGNATION

R_L	E_t	I	P_L	%EFF.
0	0	20	0	0
1	16.7	16.7	278.9	16.7
2	28.6	14.3	409	28.6
3	37.5	12.5	468.8	37.5
4	44.4	11.1	492.8	44.4
5	50	10	500	50
6	54.5	9.1	496.0	54.5
7	58.3	8.3	483.9	58.3
8	61.6	7.7	474.3	61.6
9	64.3	7.1	456.5	64.3
10	66.7	6.7	446.9	66.7
20	80	4	320	80
30	85.7	2.9	248.5	85.7
40	88.9	2.2	195.6	88.9
50	90.9	1.9	172.7	90.9

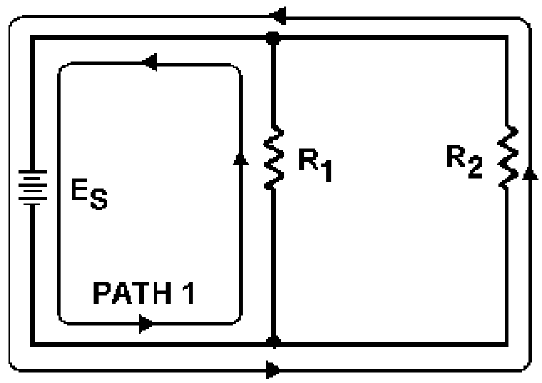
(B)
CHART



(C)
GRAPH

POWER TRANSFER in a circuit is highest when the resistance of the load equals the resistance of the source.

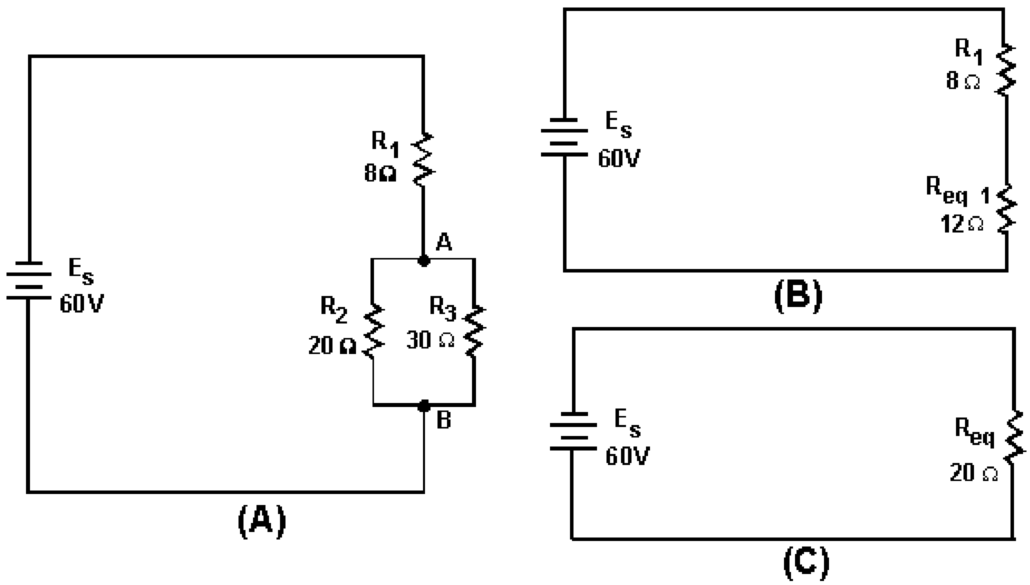
A PARALLEL CIRCUIT is a circuit having more than one current path connected to a common voltage source.



RULES FOR PARALLEL DC CIRCUITS:

- The same voltage exists across each branch of a parallel circuit and is equal to the source voltage.
- The current through a branch of a parallel network is inversely proportional to the amount of resistance of the branch.
- The total current of a parallel circuit is equal to the sum of the currents of the individual branches of the circuit.
- The total resistance of a parallel circuit is equal to the reciprocal of the sum of the reciprocals of the individual resistances of the circuit.
- The total power consumed in a parallel circuit is equal to the sum of the power consumptions of the individual resistances.

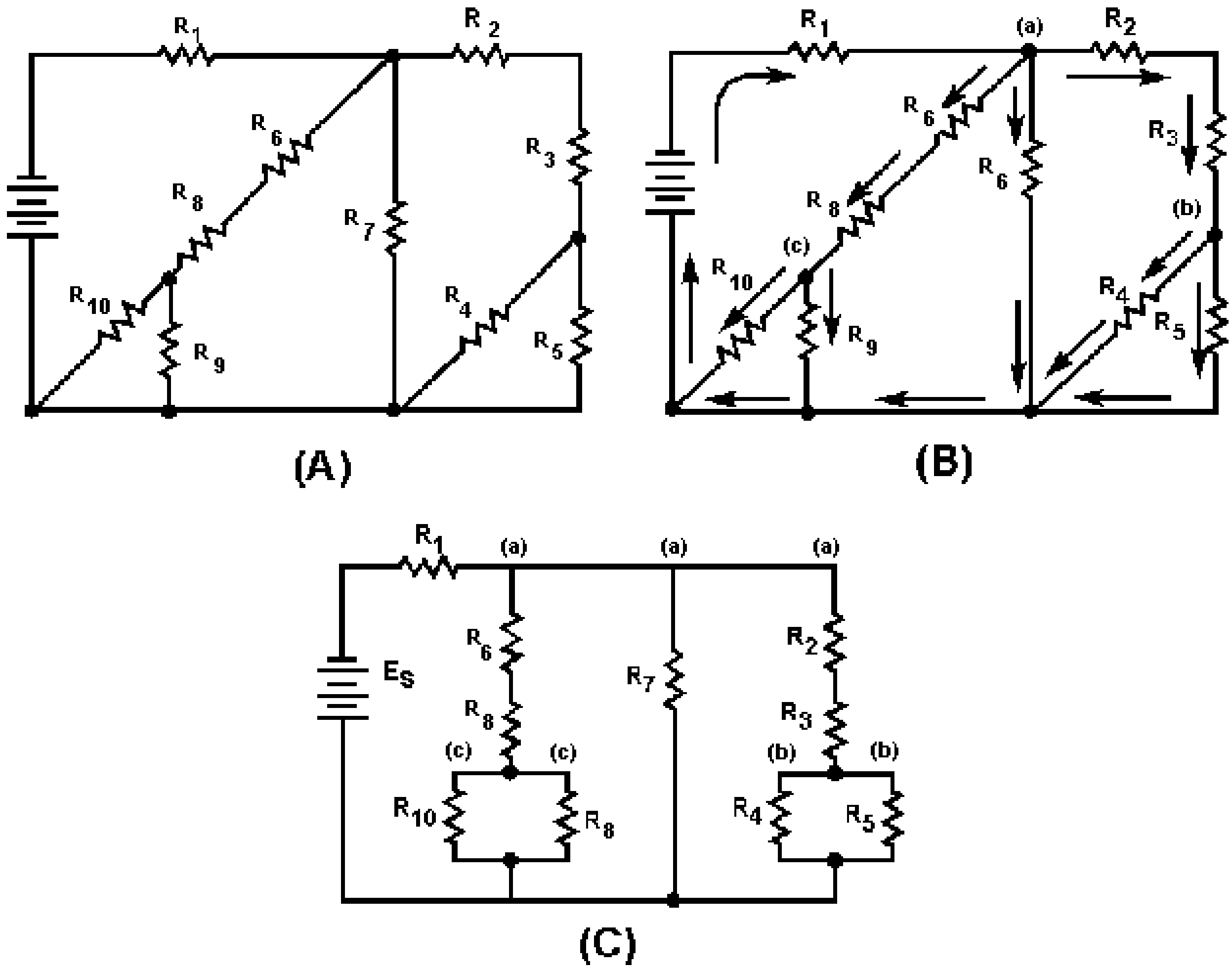
THE SOLUTION OF A COMBINATION CIRCUIT is a matter of applying the laws and rules for series and parallel circuits as applicable.



ALL PARALLEL CIRCUITS ARE COMBINATION CIRCUITS when the internal resistance of the source is taken into account.

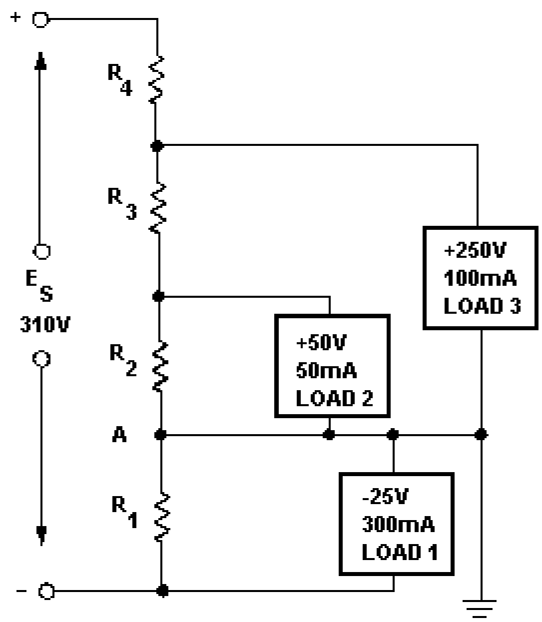
REDRAWING CIRCUITS FOR CLARITY is accomplished in the following steps:

1. Trace the current paths in the circuit.
2. Label the junctions in the circuit.
3. Recognize points which are at the same potential.
4. Visualize rearrangements, "stretching" or "shrinking," of connecting wires.
5. Redraw the circuit into simpler form (through stages if necessary).



EQUIPMENT PROTECTION from short-circuit current is accomplished by use of fuses and other circuit protection devices.

A VOLTAGE DIVIDER is a series circuit in which desired portions of the source voltage may be tapped off for use in equipment. Both negative and positive voltage can be provided to the loads by the proper selection of the reference point (ground).



ELECTRICAL SAFETY PRECAUTIONS must be observed. A fatal shock can occur from 0.1 ampere of current. Voltages as low as 30 volts have been recorded as causing sufficient current to be fatal.

ALL LIVE ELECTRICAL CIRCUITS shall be treated as potential hazards at all times.

ELECTRONIC OR ELECTRICAL EQUIPMENT discovered to be faulty or unsafe should be reported immediately to proper authority.

ELECTRICAL OR ELECTRONIC EQUIPMENT should be used and repaired by authorized personnel only.

A CO_2 EXTINGUISHER should be used to extinguish electrical fires.

FIRST AID FOR ELECTRICAL SHOCK includes the following actions:

- Remove the victim from the source of the shock.
- Check the victim to see if the person is breathing.
- If the victim is not breathing, give artificial ventilation. The preferred method is mouth-to-mouth.
- CPR may be necessary if the heartbeat has stopped, but do not attempt this unless you have been trained in its use. OBTAIN MEDICAL ASSISTANCE AS SOON AS POSSIBLE.

ANSWERS TO QUESTIONS Q1. THROUGH Q61.

A1. (a) DS1, the flashlight bulb (b) BAT, the dry cell

A2. The path for current is incomplete; or, there is no path for current with S1 open.

A3. A schematic diagram.

A4. (a) Current increases (b) Current decreases

A5. (a) Current decreases (b) Current increases

A6.

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

A7. 1.25 amperes.

A8. 4 amperes.

A9. Power.

A10. By changing the circuit resistance or the voltage of the power source.

A11.

$$P = E \times I, \quad P = \frac{E^2}{R}, \quad P = I^2 \times R$$

A12. 6 amperes.

A13. A wirewound resistor.

A14. 1 kilowatt.

A15. 8,952 watt hours or 8.952 kWh.

A16. 942 (rounded to 3 places).

A17.

(a). 160 ohms
(b). 480 ohms

A18.

E_1 = 60 volts
E_2 = 180 volts
E_3 = 240 volts

A19.

E_1 = 80 volts
E_2 = 240 volts
E_3 = 320 volts

A20. The source voltage would have to be increased to 640 volts.

A21.

(a) 330 volts

(b) E_1 = 150 volts
E_2 = 180 volts

(c) 1.98 kilowatts

(d) P_1 = 900 watts
P_2 = 1.08 kilowatts

A22. The point at which current enters the resistor is assigned a negative polarity and the point at which current leaves the resistor is assigned a positive polarity.

A23. 2 amperes.

A24. 120 volts.

A25. 50 volts.

A26. Zero volts.

A27. A circuit where there is no longer a complete path for current flow.

A28. An accidental path of low resistance which passes an abnormally high amount of current.

A29. The internal (source) resistance of the battery will drop some of the voltage.

A30. When the load resistance equals the source resistance.

A31. 50 percent.

A32.

$$98 \text{ percent } \left(\frac{12.25 \text{ watts}}{12.5 \text{ watts}} \times 100 \right)$$

A33. *60 volts.*

A34. *Total current in a series circuit flows through every circuit component but in a parallel circuit total current divides among the available paths.*

A35. *Whether the current is entering the junction (+) or leaving the junction (-).*

A36.

$$25 \text{ ohms } \left(R_{eq} = \frac{R}{N} \right)$$

A37.

$$6\ k\Omega \left(R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \right) \quad \text{(use powers of tens)}$$

A38.

$$7.5\ k\Omega \ \left(R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2} \right)$$

A39. *Equivalent resistor or R_{eq}.*

A40. *In both cases all the power used in the circuit must come from the source.*

A41.

$$R_T = 12\Omega \quad \left(\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right)$$

$$E_S = 120V \ \left(E_S = E_{R3} = \sqrt{P_{R3} \times R_3} \right)$$

$$I_{R2} = 4A \quad \left(I_{R2} = \frac{E_S}{R_2} \right)$$

A42. *$P_T = 60$ W, $E_{R2} = 10$ V.*

A43. *4Ω.*

A44. *25Ω.*

A45. Because of the 2-volt drop across the internal resistance, only 48 volts is available for the rest of the circuit.

A46. (a) Total resistance increases, total current decreases (b) Total resistance becomes infinite, total current is equal to zero

A47. (a) Total resistance decreases, total current increases (b) Total resistance decreases, total current increases

A48. None.

A49. The source voltage and load requirements (voltage and current).

A50. 45 mA rule-of-thumb.

A51. 2 kΩ.

A52. 495 mA.

A53. R_1 is the bleeder resistor. Bleeder current must be known before any of the remaining divider resistor ohmic values can be computed.

A54. (a) By adding the bleeder current (I_{R1}) and the current through load 1(b) By subtracting the voltage of load 1 from the voltage of load 2.

A55. 1.35 watts.

A56. The series-parallel network drops the remaining source voltage and is used to take the place of a single resistor (75 ohms) when the required ohmic value is not available in a single resistor.

A57. R_3 = 2 watts; R_5 = 6 watts.

A58. The ground (reference point) is placed in the proper point in the voltage divider so that positive and negative voltages are supplied.

A59. NEVER! All energized electric circuits should be considered potentially dangerous.

A60. You should immediately report this condition to a qualified technician.

A61. Only trained, qualified personnel.

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Course № E-10001

Electrical Engineering 10 PDH Package

Section 3

Control of Hazardous Energy – Lockout/Tagout

Continuing Education for Engineers

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Control of Hazardous Energy

Lockout/Tagout

OSHA 3120
2002 (Revised)

OSHA Occupational Safety and Health Administration

U.S. Department of Labor

Control of Hazardous Energy
Lockout/Tagout

U.S. Department of Labor
Elaine L. Chao, Secretary

Occupational Safety and Health Administration
John L. Henshaw, Assistant Secretary

OSHA 3120
2002 (Revised)

Contents

How should I use this booklet?

This booklet presents OSHA's general requirements for controlling hazardous energy during service or maintenance of machines or equipment. It is not intended to replace or to supplement OSHA standards regarding the control of hazardous energy. After reading this booklet, employers and other interested parties are urged to review the OSHA standards on the control of hazardous energy to gain a complete understanding of the requirements regarding the control of hazardous energy. These standards, as well as other relevant resources, are identified throughout this publication.

What is "lockout/tagout"?

"Lockout/tagout" refers to specific practices and procedures to safeguard employees from the unexpected energization or startup of machinery and equipment, or the release of hazardous energy during service or maintenance activities.[1] This requires, in part, that a designated individual turns off and disconnects the machinery or equipment from its energy source(s) before performing service or maintenance and that the authorized employee(s) either lock or tag the energy-isolating device(s) to prevent the release of hazardous energy and take steps to verify that the energy has been isolated effectively. If the potential exists for the release of hazardous stored energy or for the reaccumulation of stored energy to a hazardous level, the employer must ensure that the employee(s) take steps to prevent injury that may result from the release of the stored energy.

Lockout devices hold energy-isolation devices in a safe or "off" position. They provide protection by preventing machines or equipment from becoming energized because they are

[1] The standard refers to servicing and maintaining "machines or equipment." Although the terms "machine" and "equipment" have distinct meanings, this booklet uses the term "machines" to refer both to machines and equipment. This is done for purposes of brevity only, and readers should not infer that it is intended to limit the scope of the standard. The term "equipment" is broad in scope and encompasses all types of equipment, including process equipment such as piping systems.

positive restraints that no one can remove without a key or other unlocking mechanism, or through extraordinary means, such as bolt cutters. Tagout devices, by contrast, are prominent warning devices that an authorized employee fastens to energy-isolating devices to warn employees not to reenergize the machine while he or she services or maintains it. Tagout devices are easier to remove and, by themselves, provide employees with less protection than do lockout devices.

Why do I need to be concerned about lockout/tagout?

Employees can be seriously or fatally injured if machinery they service or maintain unexpectedly energizes, starts up, or releases stored energy. OSHA's standard on the Control of Hazardous Energy (Lockout/Tagout), found in *Title 29 of the Code of Federal Regulations* (*CFR*) Part 1910.147, spells out the steps employers must take to prevent accidents associated with hazardous energy. The standard addresses practices and procedures necessary to disable machinery and prevent the release of potentially hazardous energy while maintenance or servicing activities are performed.

Two other OSHA standards also contain energy control provisions: *29 CFR* 1910.269 and 1910.333. In addition, some standards relating to specific types of machinery contain deenergization requirements—such as *29 CFR* 1910.179(l)(2)(i)(c) (requiring the switches to be "open and locked in the open position" before performing preventive maintenance on overhead and gantry cranes).[2] The provisions of Part 1910.147 apply in conjunction with these machine-specific standards to assure that employees will be adequately protected against hazardous energy.

[2] The standard provides a limited exception to the requirement that energy control procedures be documented. If an employer can demonstrate the existence of EACH of the eight elements listed in 1910.147(c)(4)(i), the employer is not required to document the energy control procedure. However, the exception terminates if circumstances change and ANY of the elements no longer exist.

How do I know if the OSHA standard applies to me?

If your employees service or maintain machines where the unexpected startup, energization, or the release of stored energy could cause injury, the standard likely applies to you. The standard applies to all sources of energy, including, but not limited to: mechanical, electrical, hydraulic, pneumatic, chemical, and thermal energy.

The standard does not cover electrical hazards from work on, near, or with conductors or equipment in electric utilization (premise wiring) installations, which are outlined by Subpart S of *29 CFR* Part 1910. You can find the specific lockout and tagout provisions for electrical shock and burn hazards in *29 CFR* Part 1910.333. Controlling hazardous energy in installations for the exclusive purpose of power generation, transmission, and distribution, including related equipment for communication or metering, is covered by *29 CFR* 1910.269.

The standard also does not cover the agriculture, construction, and maritime industries or oil and gas well drilling and servicing. Other standards concerning the control of hazardous energy, however, apply in many of these industries/situations.

When does the standard not apply to service and maintenance activities performed in industries covered by Part 1910?

The standard does not apply to general industry service and maintenance activities in the following situations, when:

- Exposure to hazardous energy is controlled completely by unplugging the equipment from an electric outlet and where the employee doing the service or maintenance has exclusive control of the plug. This applies only if electricity is the only form of hazardous energy to which employees may be exposed. This exception encompasses many portable hand tools and some cord and plug connected machinery and equipment.

- An employee performs hot-tap operations on pressurized pipelines that distribute gas, steam, water, or petroleum products, for which the employer shows the following:
  - Continuity of service is essential;
  - Shutdown of the system is impractical; and
  - The employee follows documented procedures and uses special equipment that provides proven, effective employee protection.

- The employee is performing minor tool changes or other minor servicing activities that are routine, repetitive, and integral to production, and that occur during normal production operations. In these cases, employees must have effective, alternative protection.

How does the standard apply to general industry service and maintenance operations?

The standard applies to the control of hazardous energy when employees are involved in service or maintenance activities such as constructing, installing, setting up, adjusting, inspecting, modifying, and maintaining or servicing machines or equipment. These activities include lubricating, cleaning or unjamming machines, and making adjustments or tool changes, where the employees may be exposed to hazardous energy.

If a service or maintenance activity is part of the normal production operation, the employee performing the servicing may be subjected to hazards not normally associated with the production operation itself. Although machine guarding provisions in Subpart O of *29 CFR* 1910 cover most normal production operations, workers doing service or maintenance activities during normal production operations must follow lockout/tagout procedures if they:

- Remove or bypass machine guards or other safety devices,

- Place any part of their bodies in or near a machine's point of operation, or

- Place any part of their bodies in a danger zone associated with machine operations.

Work involving minor tool changes and adjustments or other minor servicing activities that are routine, repetitive, and integral to the use of the production equipment and that occur during normal production operations are not covered by the lockout/tagout standard. This exception is limited, however, and applies only when economic considerations prevent the use of prescribed energy-isolation measures and when the employer provides and requires alternative measures to ensure effective, alternative protection.

Whenever the standard is applicable, the machinery must be shut off and isolated from its energy sources, and lockout or tagout devices must be applied to the energy-isolation devices. In addition, the authorized employee(s) must take steps to verify that he or she has effectively isolated the energy. When there is stored or residual energy, the authorized employee(s) must take steps to render that energy safe. If the possibility exists for reaccumulation of stored energy to hazardous levels, the employer must ensure that the worker(s) perform verification steps regularly to detect such reaccumulation before it has the potential to cause injury.

What are OSHA's requirements?

OSHA's standard establishes minimum performance requirements for controlling hazardous energy. The standard specifies that employers must establish an energy-control program to ensure that employees isolate machines from their energy sources and render them inoperative before any employee services or maintains them.

As part of an energy-control program, employers must:

- Establish energy-control procedures for removing the energy supply from machines and for putting appropriate lockout or tagout devices on the energy-isolating devices to prevent unexpected reenergization. When appropriate, the procedure also must address stored or potentially reaccumulated energy;
- Train employees on the energy-control program, including the safe application, use, and removal of energy controls; and
- Inspect these procedures periodically (at least annually) to ensure that they are being followed and that they remain effective in preventing employee exposure to hazardous energy.

If employers use tagout devices on machinery that can be locked out, they must adopt additional measures to provide the same level of employee protection that lockout devices would provide. Within the broad boundaries of the standard, employers have the flexibility to develop programs and procedures that meet the needs of their individual workplaces and the particular types of machines being maintained or serviced.

What must an energy-control procedure include?

Employers must develop, document, and use procedures to control potentially hazardous energy.[3] The procedures explain what employees must know and do to control hazardous energy effectively when they service or maintain machinery. If this information is the same for the various machines used at a workplace, then a single energy-control procedure may suffice. For example, similar machines (those using the same type and magnitude of energy) that have the same or similar types of control measures can be covered by a single procedure. Employers must develop separate energy-control procedures if their workplaces have more variable conditions such as multiple energy sources, different power connections, or different control sequences that workers must follow to shut down various pieces of machinery.

The energy-control procedures must outline the scope, purpose, authorization, rules, and techniques that employees will use to control hazardous energy sources, as well as the means that will be used to enforce compliance. These procedures must provide employees at least the following information:

- A statement on how to use the procedures;
- Specific procedural steps to shut down, isolate, block, and secure machines;
- Specific steps designating the safe placement, removal, and transfer of lockout/tagout devices and identifying who has responsibility for the lockout/tagout devices; and
- Specific requirements for testing machines to determine and verify the effectiveness of lockout devices, tagout devices, and other energy-control measures.

---

[3] The standard provides a limited exception to the requirement that energy control procedures be documented. If an employer can demonstrate the existence of EACH of the eight elements listed in 1910.147(c)(4)(i), the employer is not required to document the energy control procedure. However, the exception terminates if circumstances change and ANY of the elements no longer exist.

In Appendix A to 1910.147, OSHA provides a *Typical Minimal Lockout Procedure* for employers to consult when preparing their own specific energy-control procedures. The outline is a nonmandatory guideline to help employers and employees comply with the standard. Nothing in the appendix adds to or detracts from any of the requirements in the standard.

What must workers do before they begin service or maintenance activities?

Before beginning service or maintenance, the following steps must be accomplished in sequence and according to the specific provisions of the employer's energy-control procedure:

(1) Prepare for shutdown;

(2) Shut down the machine;

(3) Disconnect or isolate the machine from the energy source(s);

(4) Apply the lockout or tagout device(s) to the energy-isolating device(s);

(5) Release, restrain, or otherwise render safe all potential hazardous stored or residual energy. If a possibility exists for reaccumulation of hazardous energy, regularly verify during the service and maintenance that such energy has not reaccumulated to hazardous levels; and

(6) Verify the isolation and deenergization of the machine.

What must workers do before they remove their lockout or tagout device and reenergize the machine?

Employees who work on deenergized machinery may be seriously injured or killed if someone removes lockout/tagout devices and reenergizes machinery without their knowledge. Thus, it is extremely important that all employees respect lockout and tagout devices and that only the person(s) who applied these devices remove them.

Before removing lockout or tagout devices, the employees must take the following steps in accordance with the specific provisions of the employer's energy-control procedure:

- Inspect machines or their components to assure that they are operationally intact and that nonessential items are removed from the area; and
- Check to assure that everyone is positioned safely and away from machines.

After removing the lockout or tagout devices but before reenergizing the machine, the employer must assure that all employees who operate or work with the machine, as well as those in the area where service or maintenance is performed, know that the devices have been removed and that the machine is capable of being reenergized. (See Sections 6(e) and (f) of *29 CFR* Part 1910.147 for specific requirements.) In the rare situation in which the employee who placed the lockout/tagout device is unable to remove that device, another person may remove it under the direction of the employer, provided that the employer strictly adheres to the specific procedures outlined in the standard. (See *29 CFR* 1910.147(e)(3).)

When do I use lockout and how do I do it?

You must use a lockout program (or tagout program that provides a level of protection equal to that achieved through lockout) whenever your employees engage in service or maintenance operations on machines that are capable of being locked out and that expose them to hazardous energy from unexpected energization, startup, or release of stored energy.

The primary way to prevent the release of hazardous energy during service and maintenance activities is by using energy-isolating devices such as manually operated circuit breakers, disconnect switches, and line valves and safety blocks. Lockout requires use of a lock or other lockout device to hold the energy-isolating device in a safe position to prevent machinery from becoming reenergized. Lockout also requires employees to follow an established procedure to ensure that machinery will not be reenergized until the same employee who placed the lockout device on the energy-isolating device removes it.

How can I determine if the energy-isolating device can be locked out?

An energy-isolating device is considered “capable of being locked out” if it meets one of the following requirements:

- Is designed with a hasp or other part to which you can attach a lock such as a lockable electric disconnect switch;
- Has a locking mechanism built into it; or
- Can be locked without dismantling, rebuilding, or replacing the energy-isolating device or permanently altering its energy-control capability, such as a lockable valve cover or circuit breaker blockout.

What do I do if I cannot lock out the equipment?

Sometimes it is not possible to lock out the energy-isolating device associated with the machinery. In that case, you must securely fasten a tagout device as close as safely possible to the energy-isolating device in a position where it will be immediately obvious to anyone attempting to operate the device. You also must meet all of the tagout provisions of the standard. The tag alerts employees to the hazard of reenergization and states that employees may not operate the machinery to which it is attached until the tag is removed in accordance with an established procedure.

What other options do I have?

If it is possible to lock out an energy-isolating device, employers must use lockout devices unless they develop, document, and use a tagout procedure that provides employees with a level of protection equal to that provided by a lockout device. In a tagout program, an employer can attain an equal level of protection by complying with all tagout-related provisions of the standard and using at least one added safety measure that prevents unexpected reenergization. Such measures might include removing an isolating circuit element, blocking a controlling switch, opening an extra disconnecting device, or removing a valve handle to minimize the possibility that machines might inadvertently be reenergized while employees perform service and maintenance activities.

When can tagout devices be used instead of lockout devices?

When an energy-isolating device cannot be locked out, the employer must modify or replace the energy-isolating device to make it capable of being locked out or use a tagout system. Whenever employers significantly repair, renovate, or modify machinery or install new or replacement machinery, however, they must ensure that the energy-isolating devices for the machinery are capable of being locked out.

Tagout devices may be used on energy-isolating devices that are capable of being locked out if the employer develops and implements the tagout in a way that provides employees with a level of protection equal to that achieved through a lockout system.

When using a tagout system, the employer must comply with all tagout-related provisions of the standard and train employees in the limitations of tags, in addition to providing normal hazardous energy control training for all employees.

What are the limitations of tagout devices?

A tagout device is a prominent warning that clearly states that the machinery being controlled must not be operated until the tag is removed in accordance with an established procedure. Tags are essentially warning devices and do not provide the physical restraint of a lock. Tags may evoke a false sense of security. For these reasons, OSHA considers lockout devices to be more secure and more effective than tagout devices in protecting employees from hazardous energy.

What are the requirements for lockout/tagout devices?

Whether lockout or tagout devices are used, they must be the only devices the employer uses in conjunction with energy-isolating devices to control hazardous energy. The employer must provide these devices and they must be singularly identified and not used for other purposes. In addition, they must have the following characteristics:

- Durable enough to withstand workplace conditions. Tagout devices must not deteriorate or become illegible even when used with corrosive components such as acid or alkali chemicals or in wet environments.
- Standardized according to color, shape, or size. Tagout devices also must be standardized according to print and format. Tags must be legible and understandable by all employees. They must warn employees about the hazards if the machine is energized, and offer employees clear instruction such as: "Do Not Start," "Do Not Open," "Do Not Close," "Do Not Energize," or "Do Not Operate."
- Substantial enough to minimize the likelihood of premature or accidental removal. Employees should be able to remove locks only by using excessive force with special tools such as bolt cutters or other metal-cutting tools. Tag attachments must be non-reusable, self-locking, and non-releasable, with a minimum unlocking strength

of 50 pounds. Tags must be attachable by hand, and the device for attaching the tag should be a one-piece nylon cable tie or its equivalent so it can withstand all environments and conditions.

- Labeled to identify the specific employees authorized to apply and remove them.

What do employees need to know about lockout/tagout programs?

Training must ensure that employees understand the purpose, function, and restrictions of the energy-control program. Employers must provide training specific to the needs of "authorized," "affected," and "other" employees.

"Authorized" employees are those responsible for implementing the energy-control procedures or performing the service or maintenance activities. They need the knowledge and skills necessary for the safe application, use, and removal of energy-isolating devices. They also need training in the following:

- Hazardous energy source recognition;
- The type and magnitude of the hazardous energy sources in the workplace; and
- Energy-control procedures, including the methods and means to isolate and control those energy sources.

"Affected" employees (usually machine operators or users) are employees who operate the relevant machinery or whose jobs require them to be in the area where service or maintenance is performed. These employees do not service or maintain machinery or perform lockout/tagout activities. Affected employees must receive training in the purpose and use of energy-control procedures. They also need to be able to do the following:

- Recognize when the energy-control procedure is being used,

- Understand the purpose of the procedure, and
- Understand the importance of not tampering with lockout or tagout devices and not starting or using equipment that has been locked or tagged out.

All other employees whose work operations are or may be in an area where energy-control procedures are used must receive instruction regarding the energy-control procedure and the prohibition against removing a lockout or tagout device and attempting to restart, reenergize, or operate the machinery.

In addition, if tagout devices are used, all employees must receive training regarding the limitations of tags. (See *29 CFR* 1910.147(c)(7)(ii).)

When is training necessary?

The employer must provide initial training before starting service and maintenance activities and must provide retraining as necessary. In addition, the employer must certify that the training has been given to all employees covered by the standard. The certification must contain each employee's name and dates of training.

Employers must provide retraining for all authorized and affected employees whenever there is a change in the following:

- Job assignments,
- Machinery or processes that present a new hazard, or
- Energy-control procedures.

Retraining also is necessary whenever a periodic inspection reveals, or an employer has reason to believe, that shortcomings exist in an employee's knowledge or use of the energy-control procedure.

What if I need power to test or position machines, equipment, or components?

OSHA allows the temporary removal of lockout or tagout devices and the reenergization of the machine only in limited situations for particular tasks that require energization—for example, when power is needed to test or position machines, equipment, or components. However, this temporary exception applies only for the limited time required to perform the particular task requiring energization. Employers must provide effective protection from hazardous energy when employees perform these operations. The following steps must be performed in sequence before reenergization:

1. Clear tools and materials from machines.
2. Clear employees from the area around the machines.
3. Remove the lockout or tagout devices as specified in the standard.
4. Energize the machine and proceed with testing or positioning.
5. Deenergize all systems, isolate the machine from the energy source, and reapply energy-control measures if additional service or maintenance is required.

The employer must develop, document, and use energy-control procedures that establish a sequence of actions to follow whenever reenergization is required as a part of a service or maintenance activity, since employees may be exposed to significant risks during these transition periods.

What if I use outside contractors for service or maintenance procedures?

If an outside contractor services or maintains machinery, the onsite employer and the contractor must inform each other of their respective lockout or tagout procedures. The onsite employer also must ensure that employees understand and comply with all requirements of the contractor's energy-control program(s).

What if a group performs service or maintenance activities?

When a crew, department, or other group performs service or maintenance, they must use a procedure that provides all employees a level of protection equal to that provided by a personal lockout or tagout device. Each employee in the group must have control over the sources of hazardous energy while he or she is involved in service and maintenance activities covered by the standard. Personal control is achieved when each authorized employee affixes a personal lockout/tagout device to a group lockout mechanism instead of relying on a supervisor or other person to provide protection against hazardous energy. Detailed requirements of individual responsibilities are provided in *29 CFR* 1910.147(f)(3)(ii)(A) through (D). Appendix C of OSHA Directive STD 1-7.3, *29 CFR* 1910.147, the Control of Hazardous Energy (Lockout/Tagout)-Inspection Procedures and Interpretive Guidance, (September 11, 1990), provides additional guidance.

What if a shift changes during machine service or maintenance?

Employers must make sure that there is a continuity of lockout or tagout protection. This includes the orderly transfer of lockout or tagout device protection between outgoing and incoming shifts to control hazardous energy. When lockout or tagout devices remain on energy-isolation devices from a previous shift, the incoming shift members must verify for themselves that the machinery is effectively isolated and deenergized.

How often do I need to review my lockout/tagout procedures?

Employees are required to review their procedures at least once a year to ensure that they provide adequate worker protection. As part of the review, employers must correct any deviations and inadequacies identified in the energy-control procedure or its application.

What does a review entail?

The periodic inspection is intended to assure that employees are familiar with their responsibilities under the procedure and continue to implement energy-control procedures properly. The inspector, who must be an authorized person not involved in using the particular control procedure being inspected, must be able to determine the following:

- Employees are following steps in the energy-control procedure;
- Employees involved know their responsibilities under the procedure; and
- The procedure is adequate to provide the necessary protection, and what changes, if any, are needed.

For a lockout procedure, the periodic inspection must include a review of each authorized employee's responsibilities under the energy-control procedure being inspected. Where tagout is used, the inspector's review also extends to affected employees because of the increased importance of their role in avoiding accidental or inadvertent activation of the machinery. In addition, the employer must certify that the designated inspectors perform periodic inspections. The certification must specify the following:

- Machine or equipment on which the energy-control procedure was used,
- Date of the inspection,
- Names of employees included in the inspection, and
- Name of the person who performed the inspection.

What additional information does OSHA provide about lockout/tagout?

To gain a more comprehensive understanding of the requirements for controlling hazardous energy, employers and other interested persons should review the following:

- OSHA standards with provisions regarding the control of hazardous energy such as *29 CFR* 1910.147, The control of hazardous energy (lockout/tagout); *29 CFR* 1910.269, Electric power generation, transmission, and distribution; and *29 CFR* 1910.333, Selection and use of work practices. Employers in the maritime, agriculture, and construction industries are urged to review the provisions for the control of hazardous energy contained in *29 CFR* Parts 1915, 1917, 1918, 1925, and 1926.
- The regulatory preambles to *29 CFR* 1910.147 (*54 Federal Register* 36644 (September 1, 1989)) and 1910.269 (*59 Federal Register* 4320 (January 31, 1994)), which contain comments from interested parties and OSHA's explanation for the provisions of the standards.
- OSHA instructions concerning the control of hazardous energy—Directive CPL 2-1.18A, Enforcement of the Electrical Power Generation, Transmission, and Distribution Standard (October 20, 1997) and OSHA Directive STD 1-7.3, *29 CFR* 1910.147, the Control of Hazardous Energy (Lockout/Tagout)-Inspection Procedures and Interpretive Guidance, (September 11, 1990).
- OSHA letters of interpretation regarding the application of standards concerning the control of hazardous energy.

Most of these documents are available on the OSHA website at www.osha.gov.

Additionally, OSHA offers a variety of web-based tools to help educate employers and employees about the lockout/tagout standard and how to apply it in their workplace. These include the following:

- The Lockout/Tagout Interactive Training Program, which includes a tutorial, five abstracts with a detailed discussion of major lockout/tagout issues involved, and interactive case studies;
- The Lockout/Tagout Plus Expert Advisor, an interactive, expert, diagnostic software package to help users understand and apply OSHA standards that protect workers from the release of hazardous energy; and
- The Lockout/Tagout electronic Compliance Assistant Tool (eCAT), an illustrated tool to help businesses identify and correct workplace hazards.

These tools are available on the OSHA website at www.osha.gov. For the Lockout/Tagout Interactive Training Program, click on **Technical Links**. For the Expert Advisor and eCAT, click on **eTools**.

Affected employee. An employee whose job requires him/her to operate or use a machine or equipment on which servicing or maintenance is being performed under lockout or tagout, or whose job requires him/her to work in an area in which such servicing or maintenance is being performed.

Authorized employee. A person who locks out or tags out machines or equipment in order to perform servicing or maintenance on that machine or equipment. An affected employee becomes an authorized employee when that employee's duties include performing servicing or maintenance covered under the standard.

Capable of being locked out. An energy-isolating device is capable of being locked out if it has a hasp or other means of attachment to which, or through which, a lock can be affixed, or it has a locking mechanism built into it. Other energy-isolating devices are capable of being locked out, if lockout can be achieved, without the need to dismantle, rebuild, or replace the energy-isolating device or permanently alter its energy control capability.

Energized. Connected to an energy source or containing residual or stored energy.

Energy-isolating device. A mechanical device that physically prevents the transmission or release of energy, including but not limited to the following: a manually operated electrical circuit breaker; a disconnect switch; a manually operated switch by which the conductors of a circuit can be disconnected from all ungrounded supply conductors, and in addition, no pole can be operated independently; a line valve; a block; and any similar device used to block or isolate energy. Push buttons, selector switches and other control circuit-type devices are not energy-isolating devices.

Energy source. Any source of electrical, mechanical, hydraulic, pneumatic, chemical, thermal, or other energy.

Hot tap. A procedure used in the repair, maintenance, and services activities, which involve welding on a piece of equipment (pipelines, vessels, or tanks) under pressure, in order to install connections or appurtenances. It is commonly used to replace or add sections of pipeline without the interruption of service for air, gas, water, steam, and petrochemical distribution systems.

Lockout. The placement of a lockout device on an energy-isolating device, in accordance with an established procedure, ensuring that the energy-isolating device and the equipment being controlled cannot be operated until the lockout device is removed.

Lockout device. A device that uses a positive means such as a lock, either key or combination type, to hold an energy-isolating device in the safe position and prevent the energizing of a machine or equipment. Included are blank flanges and bolted slip blinds.

Normal production operations. The utilization of a machine or equipment to perform its intended production function.

Servicing and/or maintenance. Workplace activities such as constructing, installing, setting up, adjusting, inspecting, modifying, and maintaining and/or servicing machines or equipment. These activities include lubricating, cleaning or unjamming machines or equipment and making adjustments or tool changes where the employee may be exposed to the unexpected energization or startup of the equipment or release of hazardous energy.

Setting up. Any work performed to prepare a machine or equipment to perform its normal production operation.

Tagout. The placement of a tagout device on an energy-isolating device, in accordance with an established procedure, to indicate that the energy-isolating device and the equipment being controlled may not be operated until the tagout device is removed.

Tagout device. A prominent warning device, such as a tag and a means of attachment, which can be securely fastened to an energy-isolating device in accordance with an established procedure, to indicate that the energy-isolating device and the equipment being controlled may not be operated until the tagout device is removed.

How can OSHA help me?

OSHA can provide extensive help through a variety of programs, including assistance about safety and health programs, state plans, workplace consultations, voluntary protection programs, strategic partnerships, training and education, and more.

How does safety and health program management assistance help employers and employees?

Effective management of worker safety and health protection is a decisive factor in reducing the extent and severity of work-related injuries and illnesses and their related costs. In fact, an effective safety and health program forms the basis of good worker protection and can save time and money—about $4 for every dollar spent—and increase productivity.

To assist employers and employees in developing effective safety and health programs, OSHA published recommended *Safety and Health Program Management Guidelines (Federal Register* 54(18):3908-3916, January 26, 1989). These voluntary guidelines can be applied to all worksites covered by OSHA.

The guidelines identify four general elements that are critical to the development of a successful safety and health management program:

- Management leadership and employee involvement,
- Worksite analysis,
- Hazard prevention and control, and
- Safety and health training.

The guidelines recommend specific actions under each of these general elements to achieve an effective safety and health program. The *Federal Register* notice is available online at www.osha.gov.

What are state plans?

State plans are OSHA-approved job safety and health programs operated by individual states or territories instead of Federal OSHA. The *Occupational Safety and Health Act of 1970 (OSH Act)* encourages states to develop and operate their own job safety and health plans and permits state enforcement of OSHA standards if the state has an approved plan. Once OSHA approves a state plan, it funds 50 percent of the program's operating costs. State plans must provide standards and enforcement programs, as well as voluntary compliance activities that are at least as effective as those of Federal OSHA.

There are 26 state plans: 23 cover both private and public (state and local governments) employment, and 3 (Connecticut, New Jersey, and New York) cover only the public sector. For more information on state plans, see the listing at the end of this publication, or visit OSHA's website at www.osha.gov.

How can consultation assistance help employers?

In addition to helping employers identify and correct specific hazards, OSHA's consultation service provides free, onsite assistance in developing and implementing effective workplace safety and health management systems that emphasize the prevention of worker injuries and illnesses.

Comprehensive consultation assistance provided by OSHA includes a hazard survey of the worksite and an appraisal of all aspects of the employer's existing safety and health management system. In addition, the service offers assistance to employers in developing and implementing an effective safety and health management system. Employers also may receive training and education services, as well as limited assistance away from the worksite.

Who can get consultation assistance and what does it cost?

Consultation assistance is available to small employers with fewer than 250 employees at a fixed site and no more than 500 corporatewide who want help in establishing and maintaining a safe and healthful workplace.

Funded largely by OSHA, the service is provided at no cost to the employer. Primarily developed for smaller employers with more hazardous operations, the consultation service is delivered by state governments employing professional safety and health consultants. No penalties are proposed or citations issued for hazards identified by the consultant. The employer's only obligation is to correct all identified serious hazards within the agreed-upon correction time frame.

Can OSHA assure privacy to an employer who asks for consultation assistance?

OSHA provides consultation assistance to the employer with the assurance that his or her name and firm and any information about the workplace will not be routinely reported to OSHA enforcement staff.

Can an employer be cited for violations after receiving consultation assistance?

If an employer fails to eliminate or control a serious hazard within the agreed-upon timeframe, the Consultation Project Manager must refer the situation to the OSHA enforcement office for appropriate action. This is a rare occurrence, however, since employers request the service for the expressed purpose of identifying and fixing hazards in their workplaces.

What incentives does OSHA provide for seeking consultation assistance?

Under the consultation program, certain exemplary employers may request participation in OSHA's Safety and Health Achievement Recognition Program (SHARP). Eligibility for participation in SHARP includes, but is not limited to, receiving a full-service, comprehensive consultation visit, correcting all identified hazards, and developing an effective safety and health management system.

Employers accepted into SHARP may receive an exemption from programmed inspections (not complaint or accident investigation inspections) for a period of 1 year initially, or 2 years upon renewal.

For more information concerning consultation assistance, see the list of consultation offices beginning on page 34, contact your regional or area OSHA office, or visit OSHA's website at www.osha.gov.

What are the Voluntary Protection Programs?

Voluntary Protection Programs (VPPs) represent one part of OSHA's effort to extend worker protection beyond the minimum required by OSHA standards. VPP—along with onsite consultation services, full-service area offices, and OSHA's Strategic Partnership Program (OSPP)—represents a cooperative approach which, when coupled with an effective enforcement program, expands worker protection to help meet the goals of the *OSH Act*.

How does the VPP work?

There are three levels of VPPs: Star, Merit, and Demonstration. All are designed to do the following:

- Recognize employers who have successfully developed and implemented effective and comprehensive safety and health management systems;
- Encourage these employers to continuously improve their safety and health management systems;
- Motivate other employers to achieve excellent safety and health results in the same outstanding way; and
- Establish a relationship between employers, employees, and OSHA that is based on cooperation.

How does VPP help employers and employees?

VPP participation can mean the following:

- Reduced numbers of worker fatalities, injuries, and illnesses;
- Lost-workday case rates generally 50 percent below industry averages;
- Lower workers' compensation and other injury- and illness-related costs;
- Improved employee motivation to work safely, leading to a better quality of life at work;
- Positive community recognition and interaction;
- Further improvement and revitalization of already-good safety and health programs; and
- A positive relationship with OSHA.

How does OSHA monitor VPP sites?

OSHA reviews an employer's VPP application and conducts a VPP Onsite Evaluation to verify that the safety and health management systems described are operating effectively at the site. OSHA conducts onsite evaluations on a regular basis, annually for participants at the Demonstration level, every 18 months for Merit, and every 3 to 5 years for Star. Each February, all participants must send a copy of their most recent annual evaluation to their OSHA regional office. This evaluation must include the worksite's record of injuries and illnesses for the past year.

Can OSHA inspect an employer who is participating in the VPP?

Sites participating in VPP are not scheduled for regular, programmed inspections. OSHA handles any employee complaints, serious accidents, or significant chemical releases that may occur at VPP sites according to routine enforcement procedures.

Additional information on VPP is available from OSHA national, regional, and area offices, listed beginning on page 34. Also, see Outreach at OSHA's website at www.osha.gov.

How can a partnership with OSHA improve worker safety and health?

OSHA has learned firsthand that voluntary, cooperative partnerships with employers, employees, and unions can be a useful alternative to traditional enforcement and an effective way to reduce worker deaths, injuries, and illnesses. This is especially true when a partnership leads to the development and implementation of a comprehensive workplace safety and health management system.

What is OSHA's Strategic Partnership Program (OSPP)?

OSHA Strategic Partnerships are alliances among labor, management, and government to foster improvements in workplace safety and health. These partnerships are voluntary, cooperative relationships between OSHA, employers, employee representatives, and others such as trade unions, trade and professional associations, universities, and other government agencies. OSPPs are the newest member of OSHA's family of cooperative programs.

What do OSPPs do?

These partnerships encourage, assist, and recognize the efforts of the partners to eliminate serious workplace hazards and achieve a high level of worker safety and health. Whereas OSHA's Consultation Program and VPP entail one-on-one relationships between OSHA and individual worksites, most strategic partnerships seek to have a broader impact by building cooperative relationships with groups of employers and employees.

What are the different kinds of OSPPs?

There are two major types:

- Comprehensive, which focuses on establishing comprehensive safety and health management systems at partnering worksites; and
- Limited, which helps identify and eliminate hazards associated with worker deaths, injuries, and illnesses, or have goals other than establishing comprehensive worksite safety and health programs.

OSHA is interested in creating new OSPPs at the national, regional, and local levels. OSHA also has found limited partnerships to be valuable. Limited partnerships might address the elimination or control of a specific industry hazard.

What are the benefits of participation in the OSPP?

Like VPP, OSPP can mean the following:

- Fewer worker fatalities, injuries, and illnesses;
- Lower workers' compensation and other injury- and illness-related costs;
- Improved employee motivation to work safely, leading to a better quality of life at work and enhanced productivity;
- Positive community recognition and interaction;
- Development of or improvement in safety and health management systems; and
- Positive interaction with OSHA.

For more information about this program, contact your nearest OSHA office or go to the agency website at www.osha.gov.

Does OSHA have occupational safety and health training for employers and employees?

Yes. The OSHA Training Institute in Des Plaines, IL, provides basic and advanced training and education in safety and health for federal and state compliance officers, state consultants, other federal agency personnel, and private-sector employers, employees, and their representatives.

Institute courses cover diverse safety and health topics including electrical hazards, machine guarding, personal protective equipment, ventilation, and ergonomics. The facility includes classrooms, laboratories, a library, and an audiovisual unit. The laboratories contain various demonstrations and equipment, such as power presses, woodworking and welding shops, a complete industrial ventilation unit, and a sound demonstration laboratory. More than 57 courses dealing with subjects such as safety and health in the construction industry and methods of compliance with OSHA standards are available for personnel in the private sector.

In addition, OSHA's 73 area offices are full-service centers offering a variety of informational services such as personnel for speaking engagements, publications, audiovisual aids on workplace hazards, and technical advice.

Does OSHA give money to organizations for training and education?

OSHA awards grants through its Susan Harwood Training Grant Program to nonprofit organizations to provide safety and health training and education to employers and workers in the workplace. The grants focus on programs that will educate workers and employers in small business (fewer than 250 employees), train workers and employers about new OSHA standards, or a high-risk activities or hazards. Grants are awarded for 1 year and may be renewed for an additional 12 months depending on whether the grantee has performed satisfactorily.

OSHA expects each organization awarded a grant to develop a training and/or education program that addresses a safety and health topic named by OSHA, recruit workers and employers for the training, and conduct the training. Grantees are also expected to follow up with people who have been trained to find out what changes were made to reduce the hazards in their workplaces as a result of the training.

Each year OSHA has a national competition that is announced in the *Federal Register* and on the Internet at www.osha-slc.gov/Training/sharwood/sharwood.html. If you do not have access to the Internet, you can contact the OSHA Office of Training and Education, 1555 Times Drive, Des Plaines, IL 60018, (847) 297–4810, for more information.

Does OSHA have other assistance materials available?

Yes. OSHA has a variety of materials and tools available on its website at www.osha.gov. These include eTools, Expert Advisors, Electronic Compliance Assistance Tools (eCATS), Technical Links, regulations, directives, publications, videos, and other information for employers and employees. OSHA's software programs and compliance assistance tools walk you through challenging safety and health issues and common problems to find the best solutions for your workplace. OSHA's comprehensive publications program includes more than 100 titles to help you understand OSHA requirements and programs.

OSHA's CD-ROM includes standards, interpretations, directives, and more and can be purchased on CD-ROM from the U.S. Government Printing Office. To order, write to the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402, or phone (202) 512–1800. Specify *OSHA Regulations, Documents and Technical Information on CD-ROM (ORDT)*, GPO Order No. S/N 729-013-00000-5.

What do I do in case of an emergency or to file a complaint?

To report an emergency, file a complaint, or seek OSHA advice, assistance, or products, call (800) 321–OSHA or contact your nearest OSHA regional or area office listed at the end of this publication. The teletypewriter (TTY) number is (877) 889–5627.

You can also file a complaint online and obtain more information on OSHA federal and state programs by visiting OSHA's website at www.osha.gov.

For more information on grants, training, and education, write: OSHA Training Institute, Office of Training and Education, 1555 Times Drive, Des Plaines, IL 60018; call (847) 297-4810; or see **Outreach** on OSHA's website at www.osha.gov.

OSHA Regional and Area Offices

OSHA Regional Offices

Region I
(CT,* MA, ME, NH, RI, VT*)
JFK Federal Building
Room E-340
Boston, MA 02203
Telephone: (617) 565–9860

Region II
(NJ,* NY,* PR,* VI*)
201 Varick Street
Room 670
New York, NY 10014
Telephone: (212) 337–2378

Region III
(DC, DE, MD,* PA, VA,* WV)
The Curtis Center—Suite 740 West
170 S. Independence Mall West
Philadelphia, PA 19106-3309
Telephone: (215) 861–4900

Region IV
(AL, FL, GA, KY,* MS, NC,*
SC,* TN*)
Atlanta Federal Center
61 Forsyth Street, SW, Room 6T50
Atlanta, GA 30303
Telephone: (404) 562–2300

Region V
(IL, IN,* MI,* MN,* OH, WI)
230 South Dearborn Street
Room 3244
Chicago, IL 60604
Telephone: (312) 353–2220

Region VI
(AR, LA, MN,* OK, TX)
525 Griffin Street
Room 602
Dallas, TX 75202
Telephone: (214) 767–4731

Region VII
(IA,* KS, MO, NE)
City Center Square
1100 Main Street, Suite 800
Kansas City, MO 64105
Telephone: (816) 426–5861

Region VIII
(CO, MT, ND, SD, UT,* WY*)
1999 Broadway
Suite 1690
Denver, CO 80802-5716
Telephone: (303) 844–1600

Region IX
(American Samoa, AZ,* CA,*
Guam, HI,* NV,*
Commonwealth of the
Northern Mariana Islands)
71 Stevenson Street
4th Floor
San Francisco, CA 94105
Telephone: (415) 975–4310

Region X
(AK,* ID, OR,* WA*)
1111 Third Avenue
Suite 715
Seattle, WA 98101-3212
Telephone: (206) 553–5930

* These states and territories operate their own OSHA-approved job safety and health programs (Connecticut, New Jersey, and New York plans cover public employees only). States with approved programs must have a standard that is identical to, or at least as effective as, the federal standard.

OSHA Area Offices

Anchorage, AK
(907) 271–5152

Birmingham, AL
(205) 731–1534

Mobile, AL
(334) 441–6131

Little Rock, AR
(501) 324–6291 (5818)

Phoenix, AZ
(602) 640–2348

Sacramento, CA
(916) 566–7471

San Diego, CA
(619) 557–5909

Denver, CO
(303) 844–5285

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