BASIC ELECTRICITY

CONTINUING EDUCATION
PROFESSIONAL DEVELOPMENT COURSE

Technical Learning College

Printing and Saving Instructions

TLC recommends that you download and save this pdf document and assignment to your computer desktop and open it with Adobe Acrobat DC reader.

Adobe Acrobat DC reader is a free computer software program and you can find it at Adobe Acrobat's website.

You can complete the course by viewing the course on your computer or you can print it out. This course booklet does not have the assignment (the test). Please visit our website and download the assignment (the test).

Printing Instructions: Once you have purchased the program, we will give you permission to print this document. If you are going to print this document, it was designed to be printed double-sided or duplexed but can be printed single-sided.

Hyperlink to Assignment…
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State Approval Listing Link, check to see if your State accepts or has pre-approved this course. Not all States are listed. Not all courses are listed. Do not solely trust our list for it may be outdated. It is your sole responsibility to ensure this course is accepted for credit. No refunds.

Professional Engineers; Most states will accept our courses for credit but we do not officially list the States or Agencies acceptance or approvals.

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http://www.abctlc.com/downloads/PDF/CEU%20State%20Approvals.pdf

You can obtain a printed version from TLC for an additional $169.95 plus shipping charges.

All downloads are electronically tracked and monitored for security purposes.

Important Information about this Manual

Disclaimer
This CEU training manual has been prepared to assist employees in the general awareness of the dangerous electrical system, dealing with often-complex procedures and requirements for safely handling hazardous energy. The scope of the material is quite large, requiring a major effort to bring it under control. Employee health and safety, as well as that of the public, depend upon careful application of federal and state regulations and safe working procedures.

This course will cover general electrical laws, and work rules relating to electrical principles. It should be noted, however, that the federal and state regulations are an ongoing process and subject to change over time.

This manual is a guidance document for employees who are learning general electrical principles. It is not designed to meet the full requirements of the United States Environmental Protection Agency (EPA) or the Department of Labor-Occupational Safety and Health Administration (OSHA) rules and regulations.

Only qualified licensed electricians should be allowed to work on any or all electrical installations or components. This course will not qualify you to work on any type of electrical system or component.

This course manual will provide general guidance and should not be used as a preliminary basis for developing any type of electrical or safety plan or procedure. This document is not detailed electrical procedure or electrical safety textbook or a comprehensive source book on electrical safety or building codes rules and regulations.

Technical Learning College makes no warranty, guarantee or representation as to the absolute correctness or appropriateness of the information in this manual and assumes no responsibility in connection with the implementation of this information.

It cannot be assumed that this manual contains all measures and concepts required for specific conditions or circumstances.

This document should be used for guidance and is not considered a legal document. Individuals who are responsible for electrical repairs or installation and the health and safety of workers should obtain and comply with the most recent federal, state, and local regulations relevant to these sites and are urged to consult with OSHA, the EPA and other appropriate federal, state, and local agencies.

Safety Always

1. Be Safety Conscious
Working with electrical circuits can be dangerous if you don't take certain safety precautions. Electrical shock can not only injure you but also kill you. Practice safety when working on any circuit and slow down! When you hurry through a project, there is a greater chance for an accident to occur.

2. Shut the Power Off
Always shut off the power to a circuit or device that you will be working on. This is the first thing you should do before working on any electrical circuit. I don't know anyone who has been shocked by a circuit that is not energized.

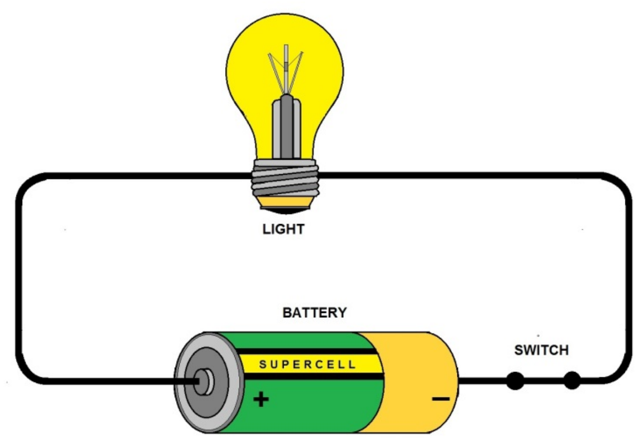
3. Test the Circuit
After turning a circuit off, it's a good idea to check it with a tester to be sure that, indeed, it is off. Never assume that the circuit is off!

4. Ladders
Ladders are necessary to accomplish some electrical jobs. Never use an aluminum ladder on any electrical project. Always use an insulated fiberglass ladder to keep you safe.

5. Wet Locations
Avoid wet areas when working with or on anything electrical. If there is a reason that you have to be in that situation, wear rubber boots and gloves to lesson your chance of getting shocked. Tools and appliances should be plugged into a GFCI outlet or GFCI extension cord.

Don't forget to dry your hands before grabbing any cord to plug it in or unplug it. Wet hands and a frayed cord don't mix. You reach down to grab the cord and just like that, you've been shocked! Believe it or not, it happens.

6. Warning Labels
Finally, if you are working on the service panel or a circuit, be sure to place a warning label on the face of the panel. This will warn someone not to turn on the circuit that you are working on. There's nothing worse than turning off the power, checking that it's off and starting to work on the circuit, only to have someone come behind you and turn the circuit back on. Always think and ask questions before turning on a breaker that is shut off. Maybe someone is working on the other end.



BASIC ELECTRICAL CIRCUIT

Some States and many employers require the final exam to be proctored.

Do not solely depend on TLC's Approval list for it may be outdated.

Most of our students prefer to do the assignment in Word and e-mail or fax the assignment back to us. We also teach this course in a conventional hands-on class. Call us and schedule a class today.

Contributing Editors

James L. Six Received a Bachelor of Science Degree in Civil Engineering from the University of Akron in June of 1976, Registered Professional Engineer in the State of Ohio, Number 45031 (Retired), Class IV Water Supply Operator issued by Ohio EPA, Number WS4-1012914-08, Class II Wastewater Collection System Operator issued by Ohio EPA, Number WC2-1012914-94

Joseph Camerata has a BS in Management with honors (magna cum laude). He retired as a Chemist in 2006 having worked in the field of chemical, environmental, and industrial hygiene sampling and analysis for 40 years.

James Bevan, Water Quality Inspector S.M.E. Twenty years of experience in the environmental field dealing with all aspects of water regulations on the federal, state, and local levels. Teacher and Proctor in Charge for Backflow Certification Testing at the ASETT Center in Tucson for the past 15 years and possess an Arizona Community College, Special Teaching Certificate in Environmental Studies.

Dr. Pete Greer S.M.E., Retired biology instructor, chemistry and biological review.

Jack White, Environmental, Health, Safety expert, City of Phoenix. Art Credits.

Technical Learning College's Scope and Function

Welcome to the Program,

Technical Learning College (TLC) offers affordable continuing education for today's working professionals who need to maintain licenses or certifications. TLC holds several different governmental agency approvals for granting of continuing education credit.

TLC's delivery method of continuing education can include traditional types of classroom lectures and distance-based courses or independent study. TLC's distance based or independent study courses are offered in a print - based distance educational format. We will beat any other training competitor's price for the same CEU material or classroom training.

Our courses are designed to be flexible and for you to finish the material at your convenience. Students can also receive course materials through the mail. The CEU course or e-manual will contain all your lessons, activities and instruction to obtain the assignments. All of TLC's CEU courses allow students to submit assignments using e-mail or fax, or by postal mail. (See the course description for more information.)

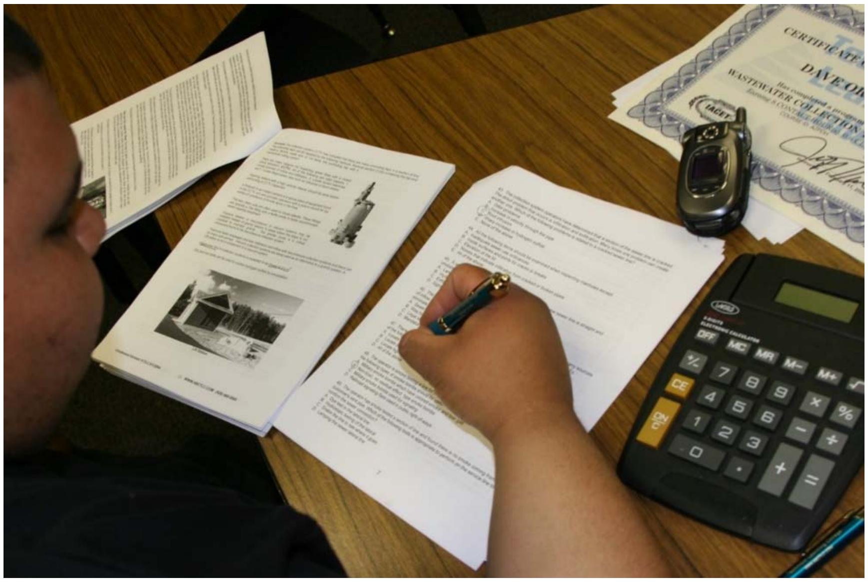
Students have direct contact with their instructor—primarily by e-mail or telephone. TLC's CEU courses may use such technologies as the World Wide Web, e-mail, CD-ROMs, videotapes and hard copies. (See the course description.) Make sure you have access to the necessary equipment before enrolling; i.e., printer, Microsoft Word and/or Adobe Acrobat Reader. Some courses may require proctored closed-book exams, depending upon your state or employer requirements.

Flexible Learning
At TLC there are no scheduled online sessions or passwords you need contend with, nor are you required to participate in learning teams or groups designed for the "typical" younger campus based student. You will work at your own pace, completing assignments in time frames that work best for you. TLC's method of flexible individualized instruction is designed to provide each student the guidance and support needed for successful course completion.

Course Structure
TLC's online courses combine the best of online delivery and traditional university textbooks. You can easily find the course syllabus, course content, assignments, and the post-exam (Assignment). This student-friendly course design allows you the most flexibility in choosing when and where you will study.

Classroom of One
TLC offers you the best of both worlds. You learn on your own terms, on your own time, but you are never on your own. Once enrolled, you will be assigned a personal Student Service Representative who works with you on an individualized basis throughout your program of study. Course specific faculty members (S.M.E.) are assigned at the beginning of each course providing the academic support you need to successfully complete each course. Please call or email us for assistance.

Satisfaction Guaranteed
We have many years of experience, dealing with thousands of students. We assure you, our customer satisfaction is second to none. This is one reason we have taught more than 20,000 students.



We welcome you to do the electronic version of the assignment and submit the answer key and registration to us either by fax or e-mail. If you need this assignment graded and a certificate of completion within a 48-hour turn around, prepare to pay an additional rush charge of $50.

Contact Numbers

Fax (928) 468-0675
Email Info@tlch2o.com
Telephone (866) 557-1746

TLC's CEU Course Description

BASIC ELECTRICTY CEU TRAINING COURSE

Review of energy and electrical systems and related electrical/math fundamentals.

This course will cover Ohm's Law, Single and Three Phase Power and general electrical principles.

- How electrical charge relates to voltage, current, and resistance.
- What voltage, current, and resistance are?
- What Ohm's Law is and how to use it to understand electricity.

You will not need any other materials for this course.

The target audience for this course includes water distribution workers, well drillers, pump installers, water treatment operators, and wastewater operators. Also included are people interested in working in a water treatment/wastewater treatment or distribution facility and/or wishing to maintain CEUs for a certification license or to learn how to perform their job safely and effectively, and/or to meet education needs for promotion. There are no prerequisites, and no other materials are needed for this course.

Course Procedures for Registration and Support

All of Technical Learning College's correspondence courses have complete registration and support services offered. Delivery of services will include, e-mail, web site, telephone, fax and mail support. TLC will attempt immediate and prompt service.

When a student registers for a distance or correspondence course, he/she is assigned a start date and an end date. It is the student's responsibility to note dates for assignments and keep up with the course work. If a student falls behind, he/she must contact TLC and request an end date extension in order to complete the course. It is the prerogative of TLC to decide whether to grant the request. All students will be tracked by a unique number assigned to the student.

Instructions for Written Assignments

The Basic Electricity CEU Training course uses a multiple choice answer key. If you should need any assistance, please email all concerns and the final test to: info@tlch2o.com.

You may write your answers or type out your own answer key. TLC would prefer that you utilize the answer key found on the TLC website under Assignments and e-mail the answer key to TLC, but it is not required. You may also fax the answer key. Please call us a couple hours later to ensure we received your information.

Feedback Mechanism (examination procedures)

Each student will receive a feedback form as part of their study packet. You will be able to find this form in the front of the course assignment or lesson.

Security and Integrity

All students are required to do their own work. All lesson sheets and final exams are not returned to the student to discourage sharing of answers. Any fraud or deceit and the student will forfeit all fees and the appropriate agency will be notified.

Grading Criteria
TLC will offer the student either pass/fail or a standard letter grading assignment. If TLC is not notified, you will only receive a pass/fail notice.

Required Texts
The Basic Electricity CEU Training course will not require any other materials. This course comes complete. No other materials are needed.

Recordkeeping and Reporting Practices
TLC will keep all student records for a minimum of seven years. It is the student's responsibility to give the completion certificate to the appropriate agencies.

ADA Compliance
TLC will make reasonable accommodations for persons with documented disabilities.

Students should notify TLC and their instructors of any special needs. Course content may vary from this outline to meet the needs of this particular group.

You will have 90 days from receipt of this manual to complete it in order to receive your Continuing Education Units (**CEUs**) or Professional Development Hours (**PDHs**). A score of 70% or better is necessary to pass this course.

Educational Mission

The educational mission of TLC is:
To provide TLC students with comprehensive and ongoing training in the theory and skills needed for the environmental education field,

To provide TLC students with opportunities to apply and understand the theory and skills needed for operator certification,

To provide opportunities for TLC students to learn and practice environmental educational skills with members of the community for the purpose of sharing diverse perspectives and experience,

To provide a forum in which students can exchange experiences and ideas related to environmental education,

To provide a forum for the collection and dissemination of current information related to environmental education, and to maintain an environment that nurtures academic and personal growth.

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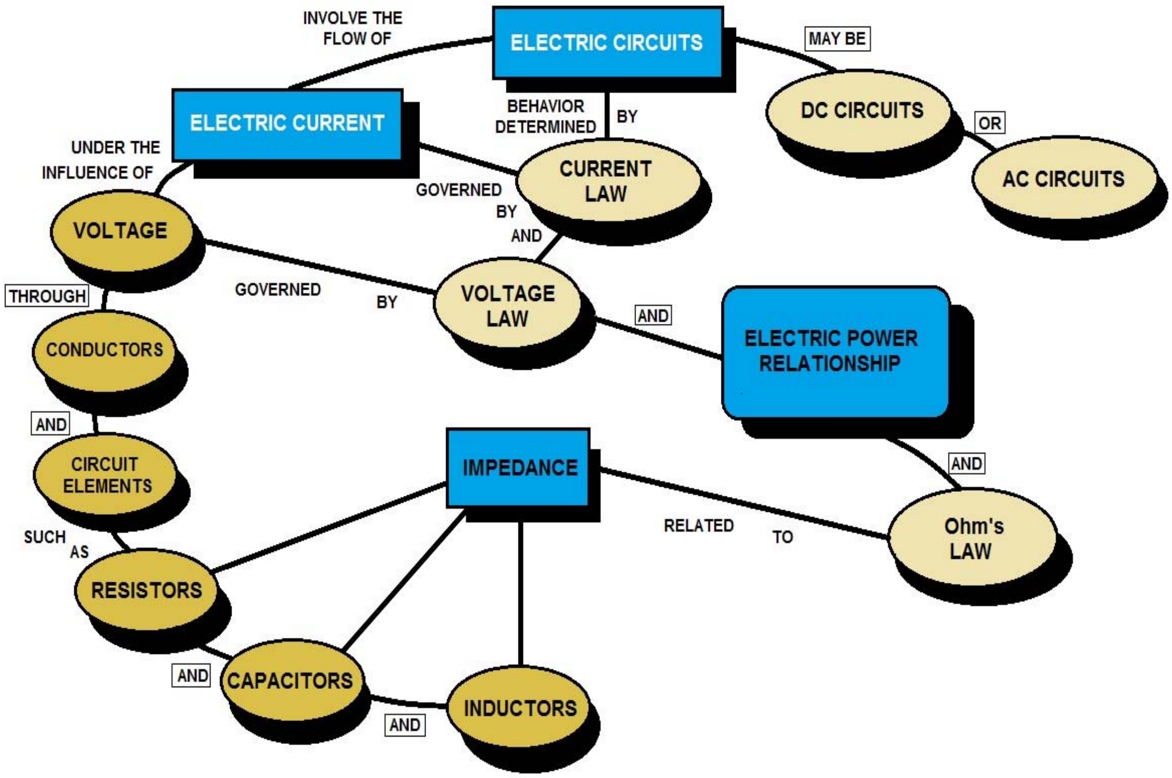


DIAGRAM OF ELECTRICAL CONCEPT

Basic Electrical Terms

AC and DC: Abbreviations for alternating current and direct current respectively.

> ***Current*** - A movement of electricity analogous to the flow of a stream of water.
> ***Direct Current*** - An electric current flowing in one direction only (i.e. current produced using a battery).
> ***Alternating Current*** - a periodic electric current that reverses its direction at regular intervals.

Accessible: Three common uses of accessible: (Wiring methods) - Capable of being removed or exposed without damaging the building structure of finish, or not permanently enclosed by such. Wires in concealed raceways are not considered accessible. (Equipment) -Admitting close approach; not guarded by locked doors or other effective means.

> ***Readily Accessible*** - Capable of being reached quickly for operation, renewal, or inspections without the requirement of climbing over or removing obstacles or use of portable ladders, chairs, etc.

Amp or Ampere: The unit of intensity of electrical current (the measure of electrical flow), is abbreviated a or A.

Box: An enclosure designed to provide access to the electrical wiring system. Uses include but are not limited to provide device and lighting outlets and wiring system junction points. Specially designed boxes are required for the support of listed ceiling fans weighing less than 35 lb (15. kg). Fans exceeding this weight limit must be supported independently of the outlet box.

Circuit Breaker: A device designed to open and close a circuit by non-automatic means and to open the circuit automatically on a predetermined over current without damaging itself when operated according to its rating.

Circuit: A complete path from the energy source through conducting bodies and back to the energy source.

Conductor: a substance or body capable of transmitting electricity. Bare - A conductor having no covering or electrical insulation whatsoever.

> ***Covered*** - A conductor encased within material of composition or thickness that is not recognized by the NEC as electrical insulation.
> ***Insulated*** - A conductor encased within material of composition or thickness that is recognized by the NEC as electrical insulation.

Device: A unit of an electrical system that is intended to carry but not utilize electricity.

Equipment: A general term including material, fittings, devices, alliances, fixtures, apparatus, and similar items used as a part of, or in connection with, an electrical installation.

Fuse: An over current protective device with a circuit opening part that is heated and broken by the passage of an over current through it.

GFCI (Ground Fault Circuit Interrupter): A device intended for the protection of personnel that de-energizes a circuit or portion of a circuit when the current to ground exceeds a preset value. "*Ground Fault*" is the name applied to this undesired circuit condition. In dwelling units (e.g. houses, apartments), GFCI protection is currently required in bathrooms, garages, outdoors, unfinished basements, kitchens and wet bar sinks. Other specific installations and/or areas may also necessitate the need for protection

Ground: A conducting connection, intentional or accidental, between an electrical circuit or equipment and the earth, or some conducting body that serves in place of the earth. Other associated terms are: Grounded conductor - A system or circuit conductor that is intentionally connected to ground. This conductor has also been referred to as the *neutral* or common conductor. Grounding conductor - a conductor used to connect equipment or the grounded circuit of a wiring system to the grounding electrode (s). Ungrounded conductor - A current carrying conductor not connected to ground.

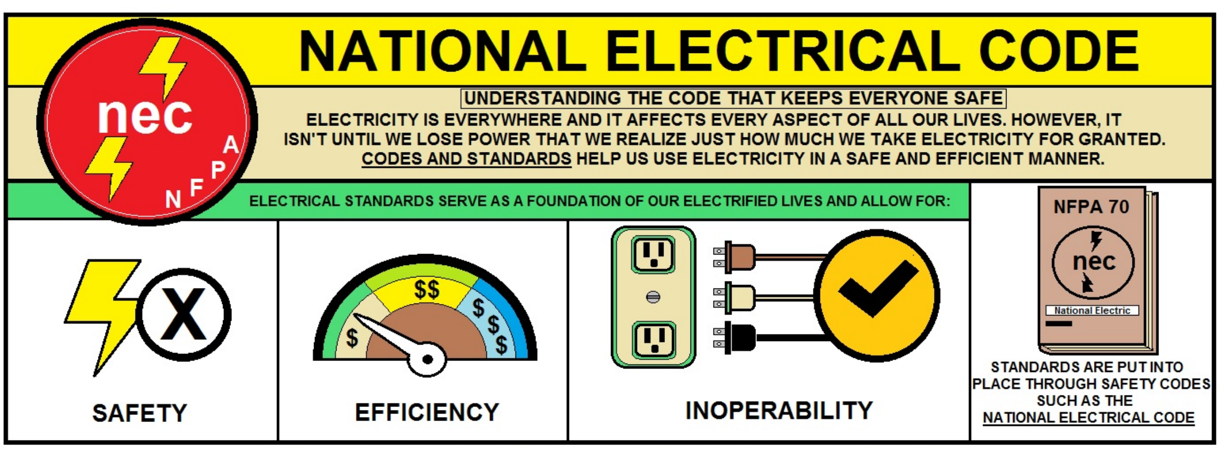
Kilowatt-hour: Work done at the steady rate equivalent to 1000 watts in one hour. Power utility companies' base their billing upon the number of kilowatt-hours (KWH) consumed.

Labeled: Equipment or materials that a label or other identifying mark of a listing organization has been attached.

Lamp: A general term for various devices for artificially producing light.

Listed: Equipment and/or materials included in a list published by an organization concerned with product evaluation and production of listed items. The listing states whether the item meets designated standards or is suitable for use in a specified manner. Listing organizations acceptable to jurisdiction authorities include Underwriters' Laboratories (UL) and CSA.

NEC (National Electrical Code): a document produced by the National Fire Protection Association for the purpose of the practical safeguarding of persons and property from hazards arising from the use of electricity. Authorities having legal jurisdiction over electrical installations adopt the code for mandatory application (i.e. incorporate the code into law).



NATIONAL ELECTRICAL CODE (NEC) BASICS

Ohm: The unit of electrical resistance and impedance, abbreviated with the symbol omega, W. Resistance is the opposition offered by a substance to the passage of electrical current. Impedance is the apparent resistance in a circuit to the flow of alternating current.

Ohm's Law: A statement of the relationship, discovered by the German scientist G. S. Ohm, between the voltage, amperage and resistance of a circuit. It states the voltage of a circuit in volts is equal to the product of the amperage in amperes and the resistance in ohms. **E=IR**

Over current: Any current in excess of the rated current or ampacity. It may result from overload, short circuit or ground fault.

Overload: Operation in excess of normal full-load rating or rated ampacity which could cause damage or dangerous overheating if continued for a sufficient time. A fault, such as a short circuit or ground fault, is not an overload. See "Over Current".

Phase: the point or stage in the period to which the rotation, oscillation, or variation has advanced relative to a standard position or starting point. *electrically,* one of the voltage sources of an alternating current electrical system whose voltage state is measured relative to a standard point.

Raceway: An enclosed channel of metallic or nonmetallic materials designed expressly for holding wires, cables, or busbars. Examples are electrical metallic tubing (EMT), flexible

Receptacle: a device installed for the connection of a single contact device. Receptacles provide a means of connecting apparatus that utilize electricity to the wiring system.

Service: the conductors and equipment for delivering electrical energy from the supply system (e.g. the electric power utility) to the wiring system of the premises served.

Single Phase: a system of alternating current power where the phase relationship between ungrounded conductors is either 0 or 10 degrees.

Three Phase: a system of alternating current power where the phase relationship between ungrounded conductors is either 0 or 120 degrees.

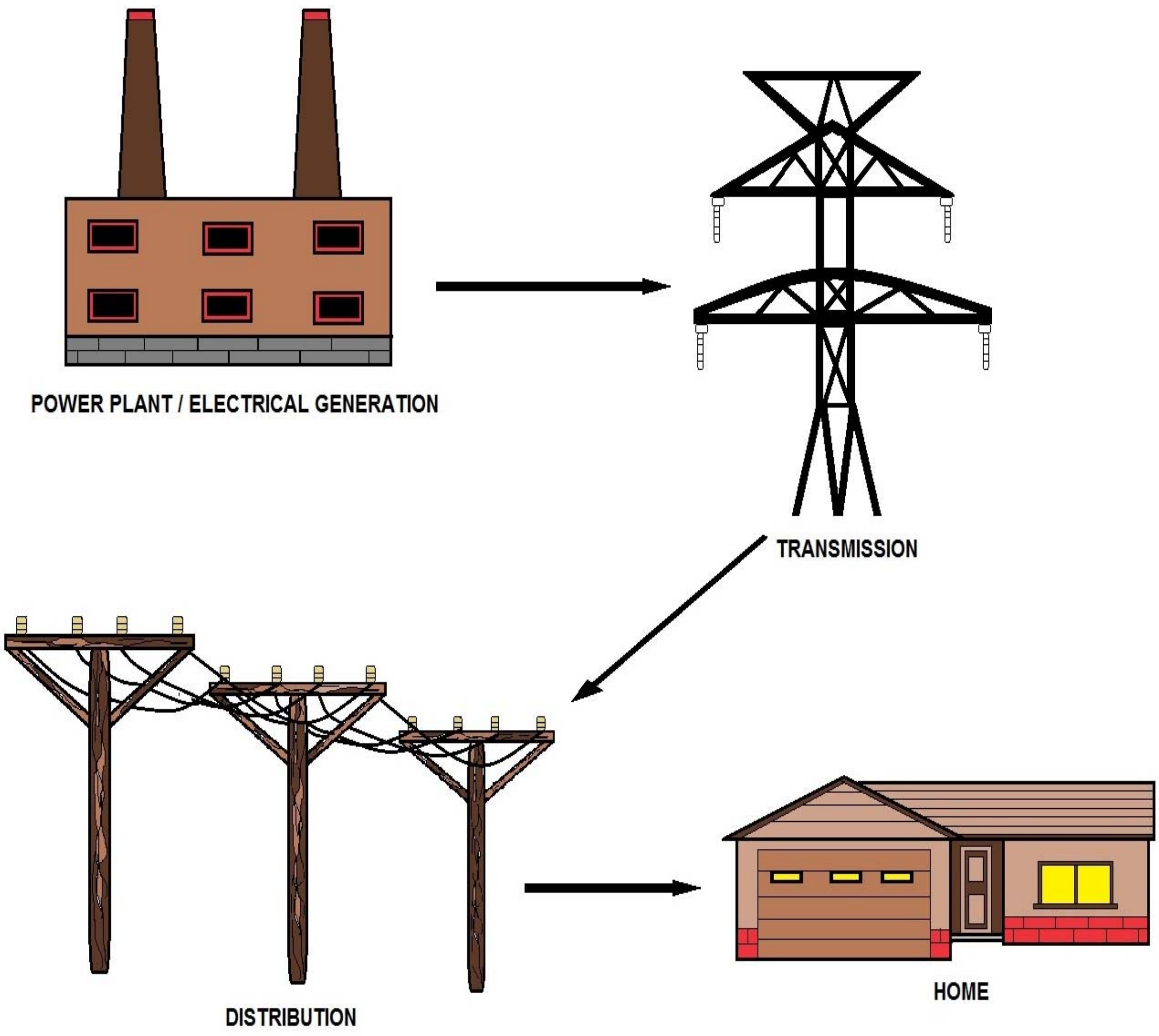
Transformer: An apparatus for converting an alternating electrical current from a high to a low potential (voltage) or vice versa. Uses of transformers include but are not limited to the conversion of utility transmission voltage to the voltage of the premises wiring system and conversion of voltage for use with chimes, alarm systems and *low-voltage* lighting. Transformers can also be used to compensate for minor variations equipment voltage requirements. Transformers only change voltage and amperage.

Volt: the unit of electromotive force, the measure of electrical pressure, is abbreviated v or V, and voltage is represented by I. The voltage (of a circuit) is the effective (greatest root-mean-square) difference of potential between any two conductors of the circuit concerned.

Some systems, such as 3-phase 4-wire and single-phase 3-wire may have multiple circuits of differing voltages. The **Nominal Voltage** is the value assigned to a circuit to conveniently designate its voltage class (e.g. 120 volts, 240 volts, 480 volts). The *actual* voltage of the circuit can vary.

Watt: the unit of power or rate of work represented by a current of one ampere under a pressure of one volt (abbreviated w or W). The English horsepower is approximately equal to 846 watts. Wattage ratings of lamps actually measure the power consumption not the illuminating capability.

Credits
Many of the definitions used are based on information contained in the National Electrical Code published by the National Fire Protection Association and Webster's New World Dictionary.

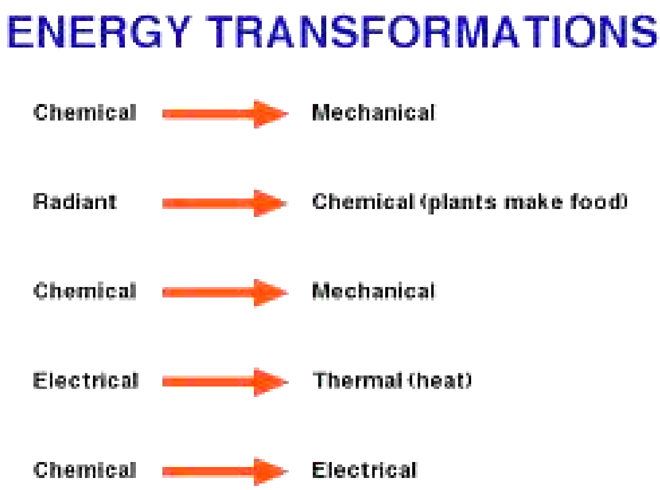


HOW ELECTRICITY GETS TO CONSUMERS (USERS)

Section 1 - Energy Introduction

Section Focus: You will learn the basics of energy and electricity. At the end of this section, you will be able to understand and describe energy with an emphasis on electricity. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: In order to understand electrical principles, we first need to explain the various properties of energy. Because this area of study is quite large and detailed, we will only focus upon the basics of electricity.



Electricity is the set of physical phenomena associated with the presence and flow of electric charge. Electricity gives a wide variety of well-known effects, such as lightning, static electricity, electromagnetic induction and electrical current. In addition, electricity permits the creation and reception of electromagnetic radiation such as radio waves.

Electromagnetic Fields
In electricity, charges produce electromagnetic fields which act on other charges. Electricity occurs due to several types of physics:

- electric charge: a property of some subatomic particles, which determines their electromagnetic interactions. Electrically charged matter is influenced by, and produces, electromagnetic fields.
- electric field (see electrostatics): an especially simple type of electromagnetic field produced by an electric charge even when it is not moving (i.e., there is no electric current). The electric field produces a force on other charges in its vicinity.
- electric potential: the capacity of an electric field to do work on an electric charge, typically measured in volts.
- electric current: a movement or flow of electrically charged particles, typically measured in amperes.
- electromagnets: Moving charges produce a magnetic field. Electrical currents generate magnetic fields, and changing magnetic fields generate electrical currents.

In electrical engineering, electricity is used for:

- electric power where electric current is used to energize equipment;
- electronics which deals with electrical circuits that involve active electrical components such as vacuum tubes, transistors, diodes and integrated circuits, and associated passive interconnection technologies.

Electrical phenomena have been studied since antiquity; though progress in theoretical understanding remained slow until the seventeenth and eighteenth centuries. Even then, practical applications for electricity were few, and it would not be until the late nineteenth century that engineers were able to put it to industrial and residential use. The rapid expansion in electrical technology at this time transformed industry and society.

Electricity's extraordinary versatility means it can be put to an almost limitless set of applications which include transport, heating, lighting, communications, and computation. Electrical power is now the backbone of modern industrial society.

When beginning to explore the world of electricity and electronics, it is vital to start by understanding the basics of voltage, current, and resistance. These are the three basic building blocks required to manipulate and utilize electricity.
At first, these concepts can be difficult to understand because we cannot "see" them. One cannot see with the naked eye the energy flowing through a wire or the voltage of a battery sitting on a table.

Even the lightning in the sky, while visible, is not truly the energy exchange happening from the clouds to the earth, but a reaction in the air to the energy passing through it. In order to detect this energy transfer, we must use measurement tools such as multimeters, spectrum analyzers, and oscilloscopes to visualize what is happening with the charge in a system. Fear not, however, this tutorial will give you the basic understanding of voltage, current, and resistance and how the three relate to each other.

GEORG OHM

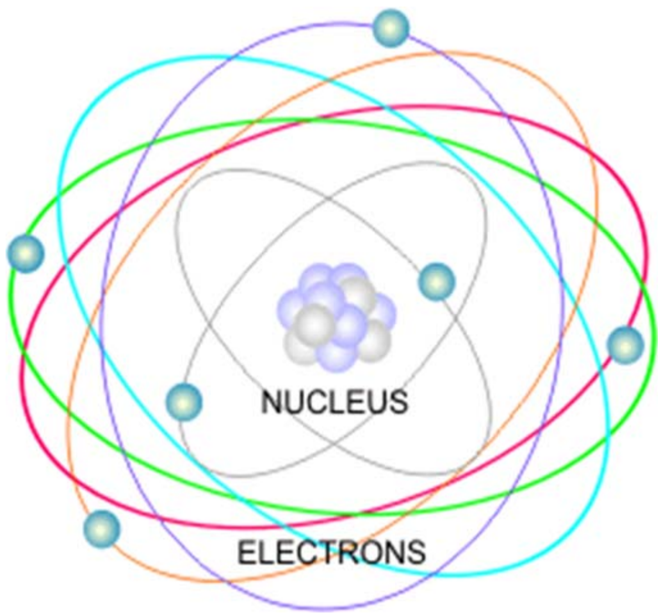
Energy Foundation

Everything Is Made of Atoms

In order to understand electricity, we need to know something about atoms. Everything in the universe is made of atoms — every star, every tree, every animal. The human body is made of atoms. Air and water are, too. Atoms are the building blocks of the universe. Atoms are so small that millions of them would fit on the head of a pin.

Atoms Are Made of Even Smaller Particles

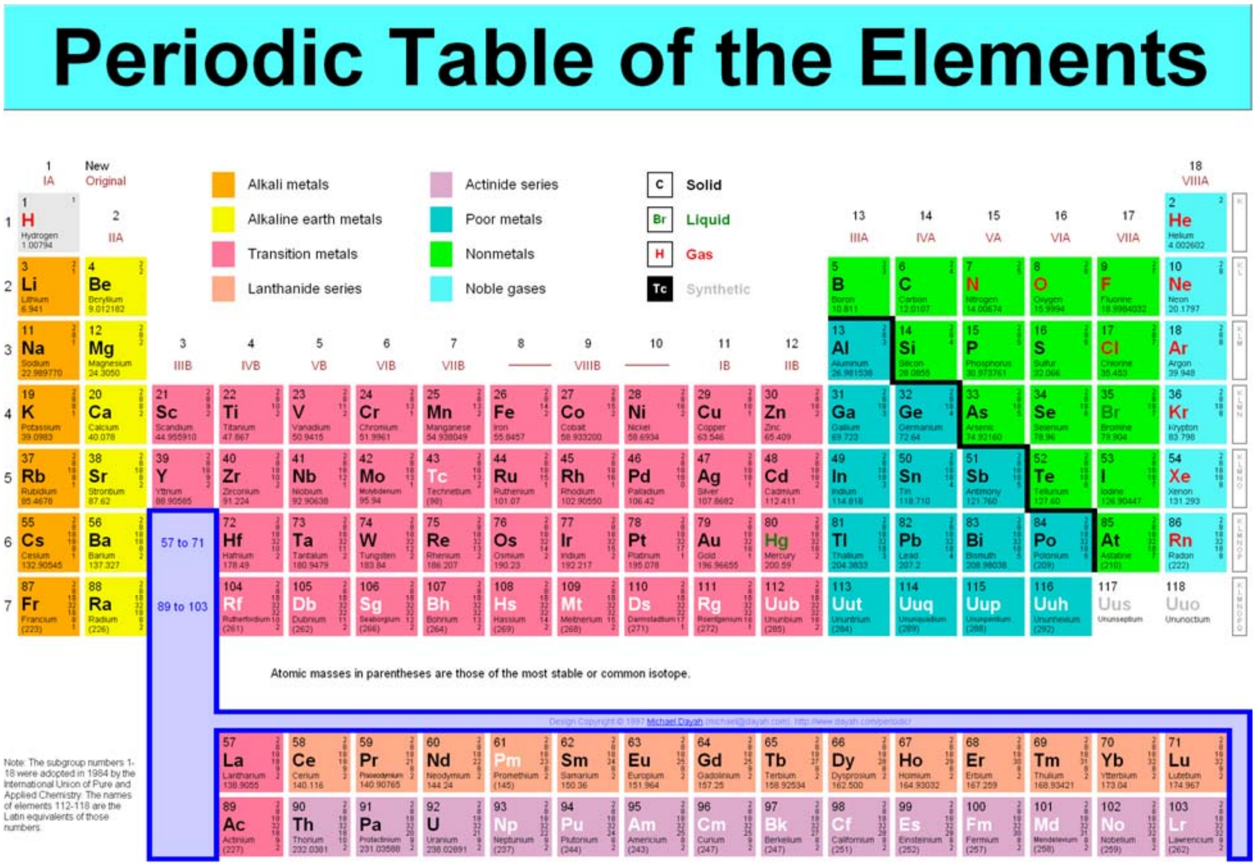
The center of an atom is called the **nucleus**. It is made of particles called **protons** and **neutrons**. The protons and neutrons are very small, but electrons are much, much smaller. **Electrons** spin around the nucleus in shells a great distance from the nucleus. If the nucleus were the size of a tennis ball, the atom would be the size of the Empire State Building. Atoms are mostly empty space.



If you could see an atom, it would look a little like a tiny center of balls surrounded by giant invisible bubbles (or shells). The electrons would be on the surface of the bubbles, constantly spinning and moving to stay as far away from each other as possible. Electrons are held in their shells by an electrical force.

The protons and electrons of an atom are attracted to each other. They both carry an electrical charge. Protons have a positive charge (+) and electrons have a negative charge (-). The positive charge of the protons is equal to the negative charge of the electrons. Opposite charges attract each other. An atom is in balance when it has an equal number of protons and electrons. The neutrons carry no charge and their number can vary.

The number of protons in an atom determines the kind of atom, or element, it is. An element is a substance consisting of one type of atom (the Periodic Table shows all the known elements), all with the same number of protons. Every atom of hydrogen, for example, has one proton, and every atom of carbon has six protons. The number of protons determines which element it is.



Periodic Table

The periodic table is a tabular arrangement of the chemical elements, organized on the basis of their atomic numbers, electron configurations (electron shell model), and recurring chemical properties. Elements are presented in order of increasing atomic number (the number of protons in the nucleus).

The standard form of the table consists of a grid of elements laid out in 18 columns and 7 rows, with a double row of elements below that. The table can also be deconstructed into four rectangular blocks: the s-block to the left, the p-block to the right, the d-block in the middle, and the f-block below that.

The rows of the table are called periods; the columns are called groups, with some of these having names such as halogens or noble gases. Since, by definition, a periodic table incorporates recurring trends, any such table can be used to derive relationships between the properties of the elements and predict the properties of new, yet to be discovered or synthesized, elements.

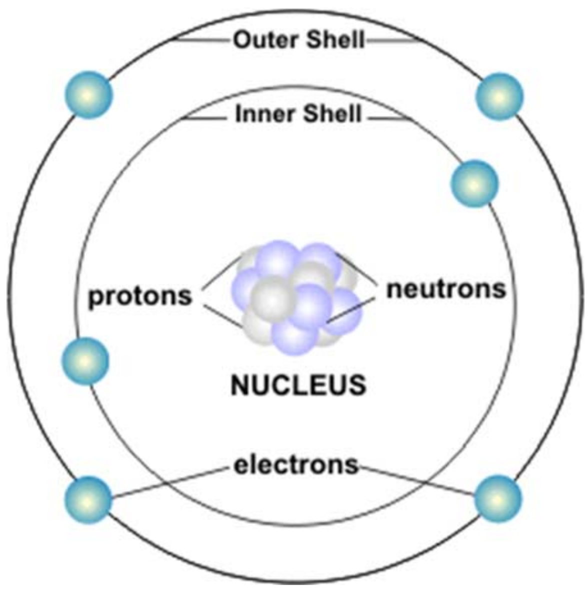
As a result, a periodic table—whether in the standard form or some other variant—provides a useful framework for analyzing chemical behavior, and such tables are widely used in chemistry and other sciences.

Electricity Is the Movement of Electrons between Atoms
Electrons, electricity, electronic and other words that begin with "electr..." all originate from the Greek word "elektor," meaning "beaming sun." In Greek, "elektron" is the word for amber.

Ancient Greeks discovered that amber behaved oddly - like attracting feathers - when rubbed by fur or other objects. They didn't know what it was that caused this phenomenon. But the

Greeks had discovered one of the first examples of static electricity.

The Latin word, electricus, means to "produce from amber by friction." So, we get our English word electricity from Greek and Latin words that were about amber.



ATOM STRUCTURE DIAGRAM

Electrons usually remain a constant distance from the nucleus in precise shells. The shell closest to the nucleus can hold two electrons. The next shell can hold up to eight. The outer shells can hold even more. Some atoms with many protons can have as many as seven shells with electrons in them.

The electrons in the shells closest to the nucleus have a strong force of attraction to the protons. Sometimes, the electrons in an atom's outermost shells do not. These electrons can be pushed out of their orbits. Applying a force can make them move from one atom to another. These moving electrons are electricity.

There are many different kinds of atoms, one for each type of element. An atom is a single part that makes up an element. There are 118 different known elements that make up everything! Some elements like oxygen we breathe are essential to life.

Each atom has a specific number of electrons, protons and neutrons. But no matter how many particles an atom has, the number of electrons usually needs to be the same as the number of protons. If the numbers are the same, the atom is called balanced, and it is very stable.

So, if an atom had six protons, it should also have six electrons. The element with six protons and six electrons is called carbon. Carbon is found in abundance in the sun, stars, comets, atmospheres of most planets, and the food we eat. Coal is made of carbon; so are diamonds.

Ions

Some kinds of atoms have loosely attached electrons. An atom that loses electrons has more protons than electrons and is positively charged. An atom that gains electrons has more negative particles and is negatively charge. A "charged" atom is called an "ion."

Electrons can be made to move from one atom to another. When those electrons move between the atoms, a current of electricity is created. The electrons move from one atom to another in a "flow." One electron is attached and another electron is lost.

This chain is similar to the fire fighter's bucket brigades in olden times. But instead of passing one bucket from the start of the line of people to the other end, each person would have a bucket of water to pour from one bucket to another. The result was a lot of spilled water and not enough water to douse the fire. It is a situation that's very similar to electricity passing along a wire and a circuit. The charge is passed from atom to atom when electricity is "passed."

Scientists and engineers have learned many ways to move electrons off of atoms. That means that when you add up the electrons and protons, you would wind up with one more proton instead of being balanced.

Since all atoms want to be balanced, the atom that has been "unbalanced" will look for a free electron to fill the place of the missing one. We say that this unbalanced atom has a "positive charge" (+) because it has too many protons.

Since it got kicked off, the free electron moves around waiting for an unbalanced atom to give it a home. The free electron charge is negative, and has no proton to balance it out, so we say that it has a "negative charge" (-).

So what do positive and negative charges have to do with electricity?

Scientists and engineers have found several ways to create large numbers of positive atoms and free negative electrons.

Since positive atoms want negative electrons so they can be balanced, they have a strong attraction for the electrons. The electrons also want to be part of a balanced atom, so they have a strong attraction to the positive atoms.

So, the positive attracts the negative to balance out.

The more positive atoms or negative electrons you have, the stronger the attraction for the other. Since we have both positive and negative charged groups attracted to each other, we call the total attraction "charge."

Joules

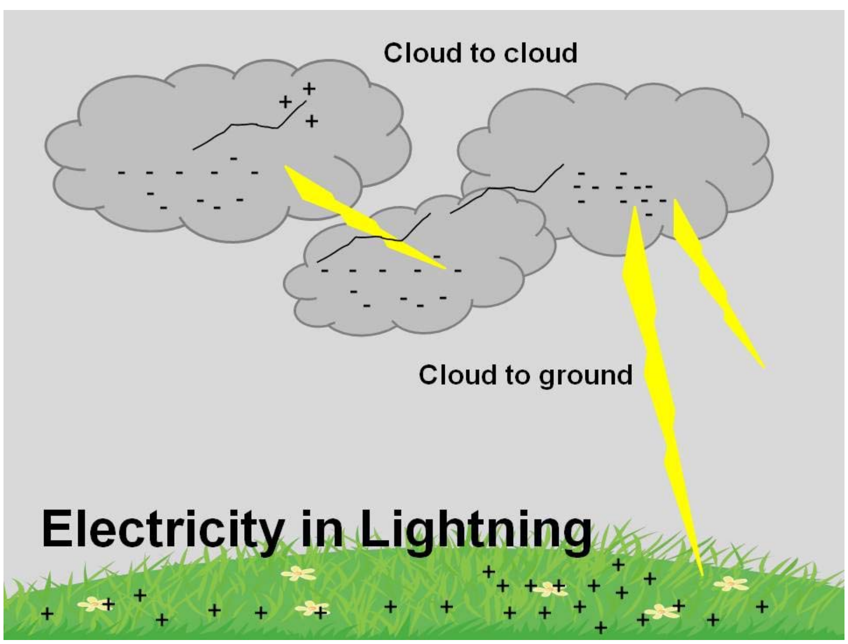
Energy also can be measured in joules. Joules sounds exactly like the word jewels, as in diamonds and emeralds. A thousand joules is equal to a British thermal unit. When electrons move among the atoms of matter, a current of electricity is created. This is what happens in a piece of wire. The electrons are passed from atom to atom, creating an electrical current from one end to other, just like in the picture.

Electricity is conducted through some things better than others do. Its resistance measures how well something conducts electricity. Some things hold their electrons very tightly. Electrons do not move through them very well. These things are called insulators. Rubber, plastic, cloth, glass and dry air are good insulators and have very high resistance.

Conductors
Other materials have some loosely held electrons, which move through them very easily. These are called conductors. Most metals – like copper, aluminum or steel – are good conductors.

Static Electricity Exists in Nature
Lightning is a form of electricity. It is electrons moving from one cloud to another or jumping from a cloud to the ground. Have you ever felt a shock when you touched an object after walking across a carpet? A stream of electrons jumped to you from that object. This is called static electricity.

Have you ever made your hair stand straight up by rubbing a balloon on it? If so, you rubbed some electrons off the balloon. The electrons moved into your hair from the balloon. They tried to get far away from each other by moving to the ends of your hair. They pushed against each other and made your hair move — they repelled each other. Just as opposite charges attract each other, like charges repel each other.

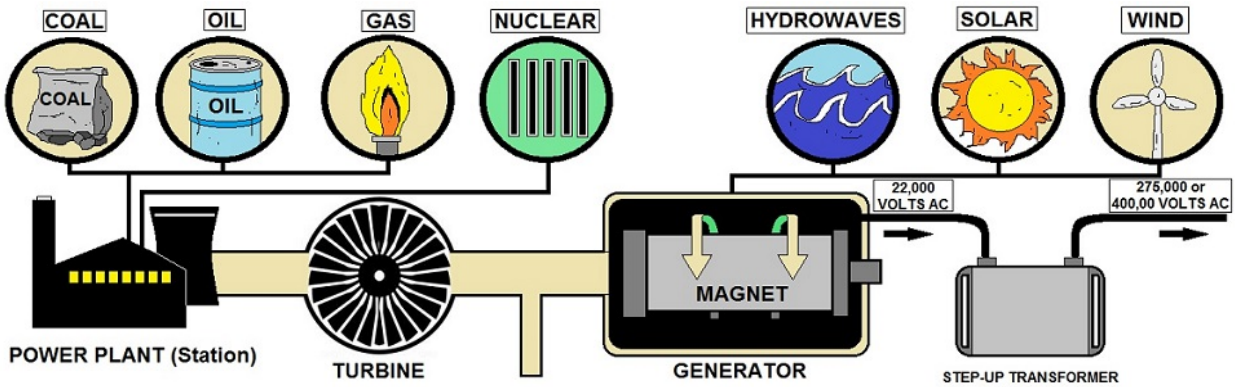


James Prescott Joule (24 December 1818 – 11 October 1889) was an English physicist and brewer, born in Salford, Lancashire. Joule studied the nature of heat, and discovered its relationship to mechanical work.

This led to the Law of conservation of energy, and this led to the development of the First law of thermodynamics. The SI derived unit of energy, the joule, is named for James Joule. He worked with Lord Kelvin to develop the absolute scale of temperature.

Joule also made observations of magnetostriction, and he found the relationship between the current through a resistor and the heat dissipated, which is now called Joule's first law.

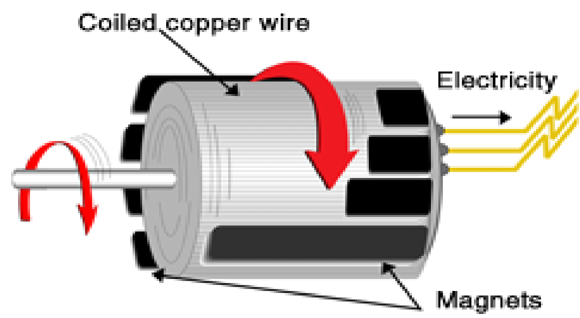
How Electricity Is Generated



ELECTRICAL TURBINE GENERATOR (STEAM)

Turbine Generator
A generator is a device that converts mechanical energy into electrical energy. The process is based on the relationship between magnetism and electricity. In 1831, scientist Michael Faraday discovered that when a magnet is moved inside a coil of wire, electrical current flows in the wire.

A typical generator at a power plant uses an electromagnet — a magnet produced by electricity — not a traditional magnet. The generator has a series of insulated coils of wire that form a stationary cylinder. This cylinder surrounds a rotary electromagnetic shaft. When the electromagnetic shaft rotates, it induces a small electric current in each section of the wire coil.



Each section of the wire becomes a small, separate electric conductor. The small currents of individual sections are added together to form one large current. This current is the electric power that is transmitted from the power company to the consumer.

An electric utility power station uses either a turbine, engine, water wheel, or other similar machine to drive an electric generator — a device that converts mechanical or chemical energy to electricity. Steam turbines, internal-combustion engines, gas combustion turbines, water turbines, and wind turbines are the most common methods to generate electricity. Steam turbine power plants powered by coal and nuclear energy produce about 70% of the electricity used in the United States. These plants are about 35% efficient. That means that for every 100 units of primary heat energy that go into a plant, only 35 units are converted to useable electrical energy. Most of the electricity in the United States is produced using steam turbines.

A turbine converts the kinetic energy of a moving fluid (liquid or gas) to mechanical energy. In a steam turbine, steam is forced against a series of blades mounted on a shaft, thus rotating the shaft connected to the generator. The generator, in turn, converts its mechanical energy to electrical energy based on the relationship between magnetism and electricity.

In steam turbines powered by fossil fuels, such as coal, petroleum (oil), and natural gas, the fuel is burned in a furnace to heat water in a boiler to produce steam.

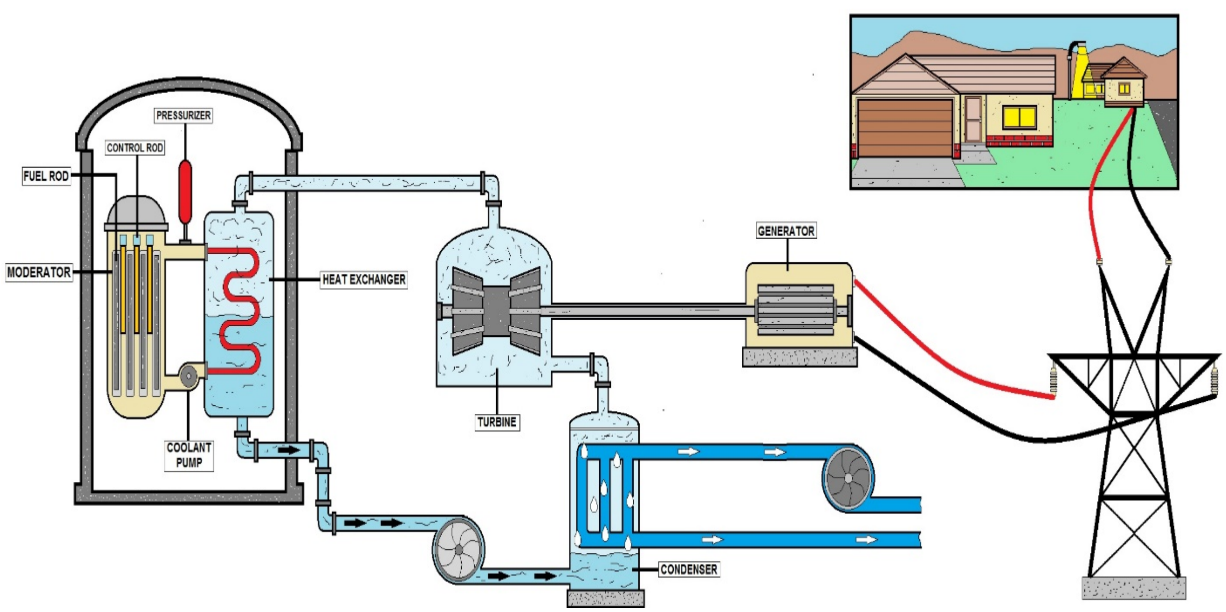
Fossil fuels generate most U.S. electricity
In 2012, coal was used for about 37% of the 4 trillion kilowatt-hours of electricity generated in the United States.

More Data
Natural gas, in addition to being burned to heat water for steam, can also be burned to produce hot combustion gases that pass directly through a turbine, spinning the turbine's blades to generate electricity. Gas turbines are commonly used when electricity utility usage is in high demand. In 2012, 30% of the U.S. electricity was fueled by natural gas.

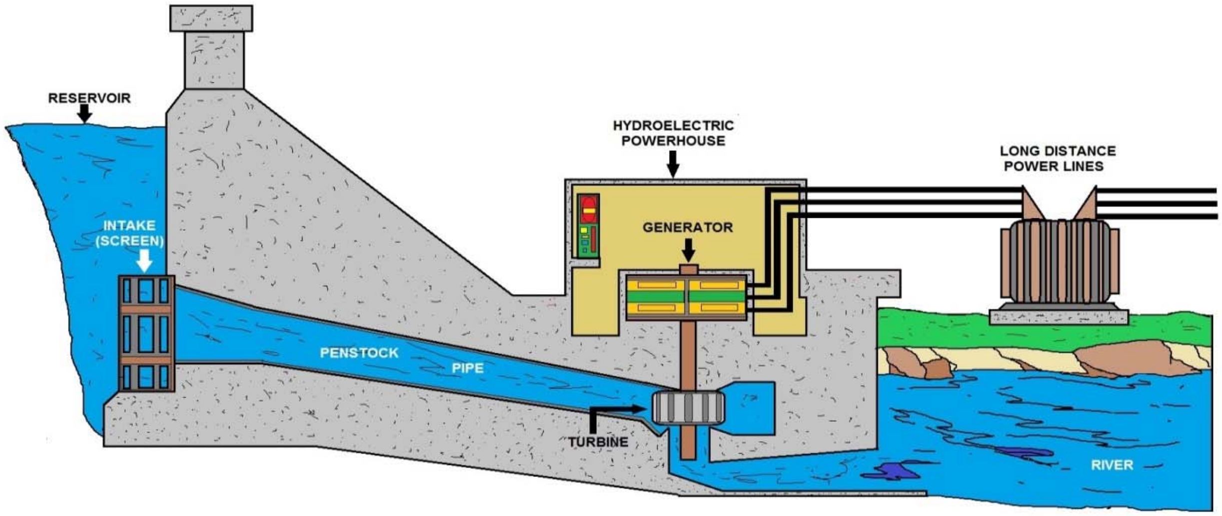
Petroleum can be burned to produce hot combustion gases to turn a turbine or to make steam to turn a turbine. Residual fuel oil, a product refined from crude oil, is often the petroleum product used in electric plants that use petroleum to make steam. Petroleum was used to generate less than 1% of all electricity in the United States in 2012.

Nuclear power provides about one-fifth of U.S. electricity
Nuclear power is a method in which steam is produced by heating water through a process called nuclear fission. In a nuclear power plant, a reactor contains a core of nuclear fuel, primarily uranium. When atoms of uranium fuel are hit by neutrons, they fission (split) releasing heat and more neutrons.

Under controlled conditions, these other neutrons can strike more uranium atoms, splitting more atoms, and so on. Thereby, continuous fission can take place, creating a chain reaction releasing heat. The heat is used to turn water into steam, which, in turn, spins a turbine that generates electricity. Nuclear power was used to generate about 19% of all U.S. electricity in 2012.



NUCLEAR ENERGY ILLUSTRATION



HYDROELECTRIC PLANT

Renewable energy sources make up the rest
Hydropower, the source for almost 7% of U.S. electricity generation in 2012, is a process in which flowing water is used to spin a turbine connected to a generator. There are two basic types of hydroelectric systems that produce electricity.

In the first system, flowing water accumulates in reservoirs created by dams. The water falls through a pipe called a penstock and applies pressure against the turbine blades to drive the generator to produce electricity.

In the second system, called run-of-river, water is diverted from a river using a relatively low dam or weir into penstocks and turbines. The dam does not store a large volume of water in a reservoir. Run-of-river power plants are more dependent on river flows than hydro plants with reservoirs for storing water which can produce electricity even when natural river flows are low.

Biomass
Biomass is material derived from plants or animals (i.e. biogenic) and includes lumber and paper mill wastes; food scraps, grass, leaves, paper, and wood in municipal solid waste (garbage); and forestry and agricultural residues such as wood chips, corn cobs, and wheat straw.

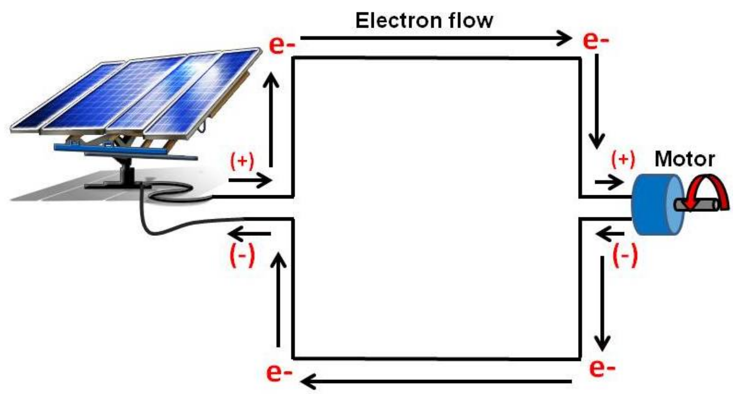
These materials can be burned directly in steam-electric power plants, or converted to gas that can be burned in steam generators, gas turbines, or internal combustion engine-generators. Biomass accounted for about 1% of the electricity generated in the United States in 2012.

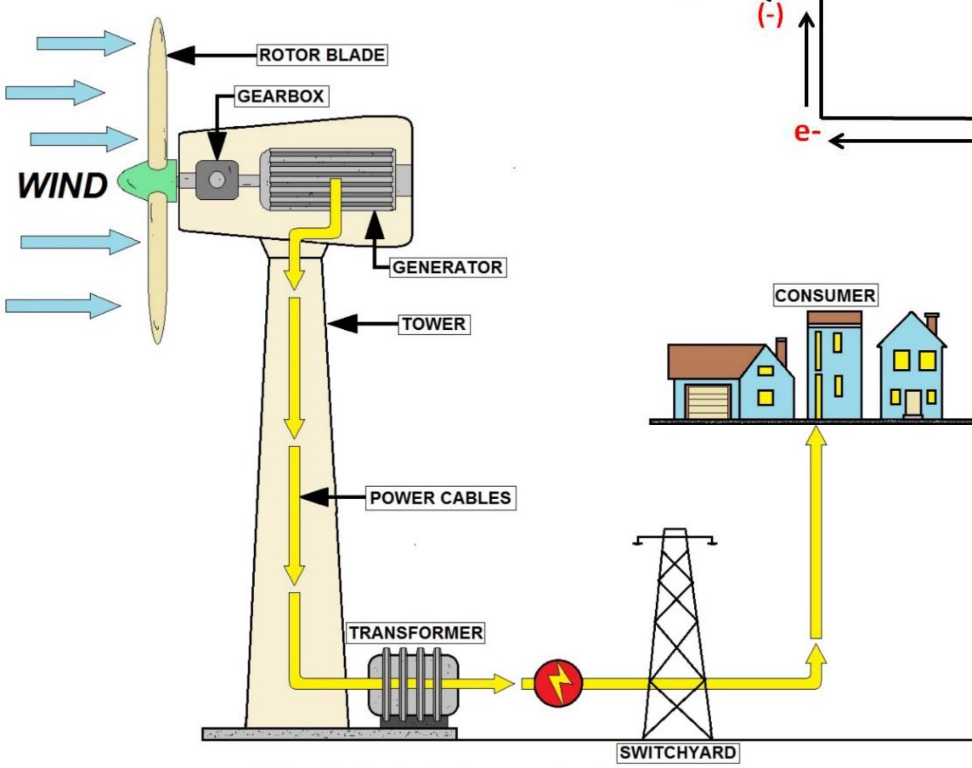
Wind power
Wind power is produced by converting wind energy into electricity. Electricity generation from wind has increased significantly in the United States since 1970, but wind power remains a small fraction of U.S. electricity generation, about 3% in 2012.

Geothermal power
Geothermal power comes from heat energy buried beneath the surface of the earth. In some areas of the United States, enough heat rises close to the surface of the earth to heat underground water into steam, which can be tapped for use at steam-turbine plants. This energy source generated less than 1% of the electricity in the United States in 2012.

Solar Power Introduction
Solar power is derived from energy from the sun. There are two main types of technologies for converting solar energy to electricity: photovoltaic (PV) and solar-thermal electric. PV conversion produces electricity directly from sunlight in a photovoltaic (solar) cell.

Solar-thermal electric generators concentrate solar energy to heat a fluid and produce steam to drive turbines. In 2012, less than 1% of the U.S. electricity generation was from solar power.





WIND POWERED GENERATOR

More on Electrical Generation and Transmission

Generation and Transmission of Electrical Energy

While this method, now known as the triboelectric effect, can lift light objects and generate sparks, it is extremely inefficient. It was not until the invention of the voltaic pile in the eighteenth century that a viable source of electricity became available. The voltaic pile, and its modern descendant, the electrical battery, store energy chemically and make it available on demand in the form of electrical energy.

The battery is a versatile and very common power source which is ideally suited to many applications, but its energy storage is finite, and once discharged it must be disposed of or recharged. For large electrical demands electrical energy must be generated and transmitted continuously over conductive transmission lines.

Electrical power is usually generated by electro-mechanical generators driven by steam produced from fossil fuel combustion, or the heat released from nuclear reactions; or from other sources such as kinetic energy extracted from wind or flowing water. The modern steam turbine invented by Sir Charles Parsons in 1884 today generates about 80 percent of the electric power in the world using a variety of heat sources.

Faraday's Homopolar Disc Generator

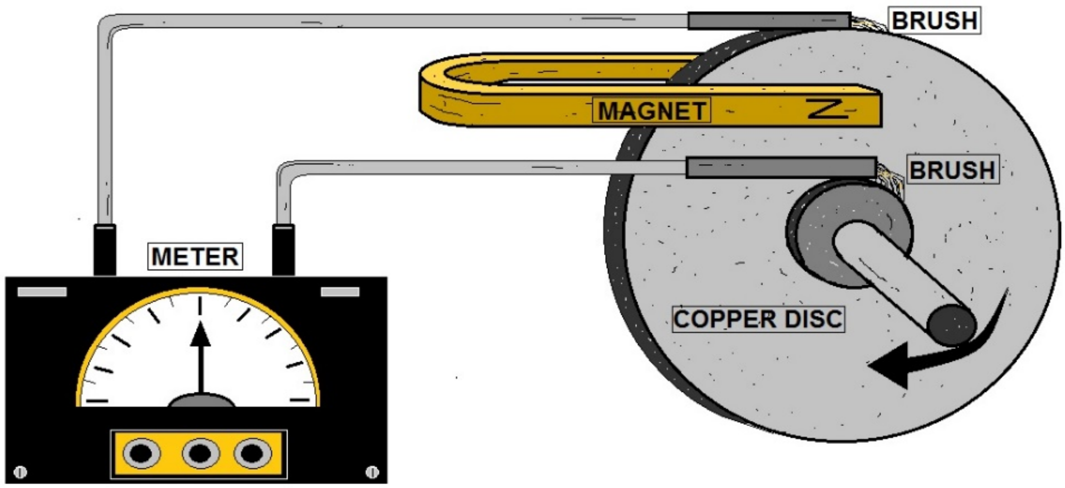
Such generators bear no resemblance to Faraday's homopolar disc generator of 1831, but they still rely on his electromagnetic principle that a conductor linking a changing magnetic field induces a potential difference across its ends. The invention in the late nineteenth century of the transformer meant that electrical power could be transmitted more efficiently at a higher voltage but lower current. Efficient electrical transmission meant in turn that electricity could be generated at centralized power stations, where it benefited from economies of scale, and then be dispatched relatively long distances to where it was needed.

Since electrical energy cannot easily be stored in quantities large enough to meet demands on a national scale, at all times exactly as much must be produced as is required.

This requires electricity utilities to make careful predictions of their electrical loads, and maintain constant co-ordination with their power stations. A certain amount of generation must always be held in reserve to cushion an electrical grid against inevitable disturbances and losses.

Demand for electricity grows with great rapidity as a nation modernizes and its economy develops. The United States showed a 12% increase in demand during each year of the first three decades of the twentieth century, a rate of growth that is now being experienced by emerging economies such as those of India or China. Historically, the growth rate for electricity demand has outstripped that for other forms of energy.

Environmental concerns with electricity generation have led to an increased focus on generation from renewable sources, in particular from wind and hydropower. While debate can be expected to continue over the environmental impact of different means of electricity production, its final form is relatively clean.



FARADAY DYNAMO SYMBOLIC EXAMPLE

Applications

Electricity is a very convenient way to transfer energy, and it has been adapted to a huge, and growing, number of uses. The invention of a practical incandescent light bulb in the 1870s led to lighting becoming one of the first publicly available applications of electrical power. Although electrification brought with it its own dangers, replacing the naked flames of gas lighting greatly reduced fire hazards within homes and factories. Public utilities were set up in many cities targeting the burgeoning market for electrical lighting.

The Joule heating effect employed in the light bulb also sees more direct use in electric heating. While this is versatile and controllable, it can be seen as wasteful, since most electrical generation has already required the production of heat at a power station. A number of countries, such as Denmark, have issued legislation restricting or banning the use of electric heating in new buildings. Electricity is however a highly practical energy source for refrigeration, with air conditioning representing a growing sector for electricity demand, the effects of which electricity utilities are increasingly obliged to accommodate.

Electricity is used within telecommunications, and indeed the electrical telegraph, demonstrated commercially in 1837 by Cooke and Wheatstone, was one of its earliest applications. With the construction of first intercontinental, and then transatlantic, telegraph systems in the 1860s, electricity had enabled communications in minutes across the globe. Optical fiber and satellite communication technology have taken a share of the market for communications systems, but electricity can be expected to remain an essential part of the process.

The effects of electromagnetism are most visibly employed in the electric motor, which provides a clean and efficient means of motive power. A stationary motor such as a winch is easily provided with a supply of power, but a motor that moves with its application, such as an electric vehicle, is obliged to either carry along a power source such as a battery, or to collect current from a sliding contact such as a pantograph.

Electronic devices make use of the transistor, perhaps one of the most important inventions of the twentieth century, and a fundamental building block of all modern circuitry.

Section 1 - Energy Introduction Post Quiz

Hyperlink to Assignment…
http://www.abctlc.com/downloads/PDF/BasicElectricityAss.pdf

1. Electrical charges produce ______________which act on other charges.

2. An electric field is a complex simple type of electromagnetic field produced by an electric charge even when moving.
A. True B. False

3. The electric field produces a _______________ on other charges in its vicinity.

4. ___________________is the capacity of an electric field to do work on an electric charge, typically measured in volts.

5. Which terms is a movement or flow of electrically charged particles, typically measured in amperes?

6. Electromagnets: Moving charges produce a magnetic field.
A. True B. False

7. Electrical currents generate_______________, and changing magnetic fields generate electrical current(s).

How Electricity Is Generated
8. A generator is a device that converts mechanical force into electrical energy.
A. True B. False

9. The generator has a series of insulated coils of wire that form a stationary cylinder. This cylinder surrounds a rotary electromagnetic shaft.
A. True B. False

10. Scientist Michael Faraday discovered that when a magnet is moved inside a coil of wire, ________________ flows in the wire.

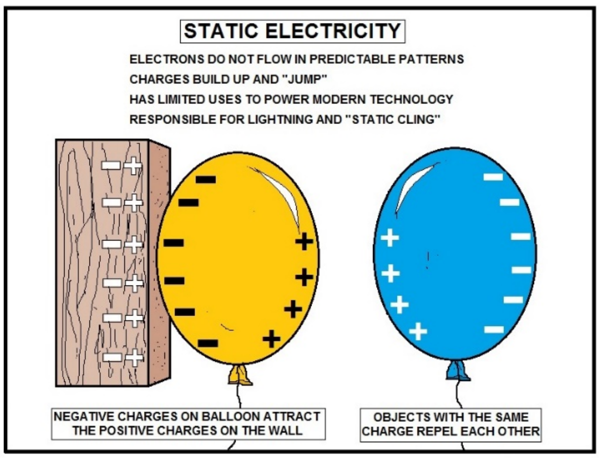
Section 1 Post Quiz Answers

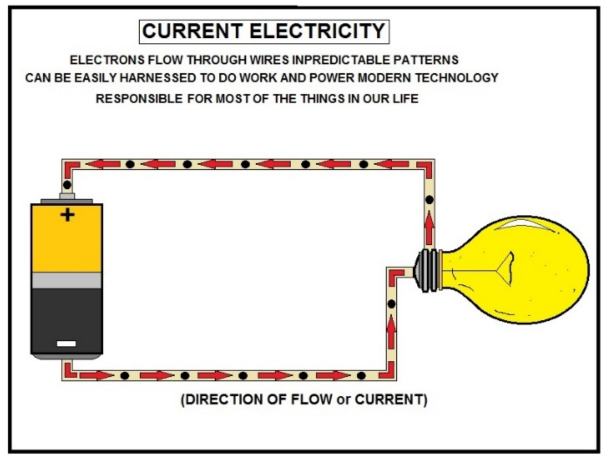
1. Electromagnetic fields
2. False
3. Force
4. Electric potential
5. Electrical current
6. True
7. Magnetic fields
8. True
9. True
10. Electrical current

Section 2 – Simple Forms of Electricity

Section Focus: You will learn the basics of simple electricity. At the end of this section, you will be able to understand and describe simple forms of electricity including electromagnetism. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: In order to understand electrical principles, we first need to explain the various simple forms of electricity. Because this area of study is quite large and detailed, we will only focus upon static and current electricity.





TWO "TYPES" OF ELECTRICITY

Static and Current Electricity
Static Electricity
Static electricity is an imbalance of electric charges within or on the surface of a material. The charge remains until it is able to move away by means of an electric current or electrical discharge. Static electricity is named in contrast with current electricity, which flows through wires or other conductors and transmits energy.

A static electric charge is created whenever two surfaces contact and separate, and at least one of the surfaces has a high resistance to electrical current (and is therefore an electrical insulator).The effects of static electricity are familiar to most people because people can feel, hear, and even see the spark as the excess charge is neutralized when brought close to a large electrical conductor (for example, a path to ground), or a region with an excess charge of the opposite polarity (positive or negative). The familiar phenomenon of a static shock–more specifically, an electrostatic discharge–is caused by the neutralization of charge.

Causes of Static Electricity
Materials are made of atoms that are normally electrically neutral because they contain equal numbers of positive charges (protons in their nuclei) and negative charges (electrons in "shells" surrounding the nucleus). The phenomenon of static electricity requires a separation of positive and negative charges. When two materials are in contact, electrons may move from one material to the other, which leaves an excess of positive charge on one material, and an equal negative charge on the other. When the materials are separated they retain this charge imbalance.

Contact-induced Charge Separation
Electrons can be exchanged between materials on contact; materials with weakly bound electrons tend to lose them while materials with sparsely filled outer shells tend to gain them. This is known as the triboelectric effect and results in one material becoming positively charged and the other negatively charged. The polarity and strength of the charge on a material once they are separated depends on their relative positions in the triboelectric series. The triboelectric effect is the main cause of static electricity as observed in everyday life, and in common high-school science demonstrations involving rubbing different materials together (e.g., fur against an acrylic rod). Contact-induced charge separation causes your hair to stand up and causes "static cling" (for example, a balloon rubbed against the hair becomes negatively charged; when near a wall, the charged balloon is attracted to positively charged particles in the wall, and can "cling" to it, appearing to be suspended against gravity).

Pressure-induced Charge Separation
Applied mechanical stress generates a separation of charge in certain types of crystals and ceramics molecules.

Heat-induced Charge Separation
Heating generates a separation of charge in the atoms or molecules of certain materials. All pyroelectric materials are also piezoelectric. The atomic or molecular properties of heat and pressure response are closely related.

Charge-induced Charge Separation
A charged object brought close to an electrically neutral object causes a separation of charge within the neutral object. Charges of the same polarity are repelled and charges of the opposite polarity are attracted. As the force due to the interaction of electric charges falls off rapidly with increasing distance, the effect of the closer (opposite polarity) charges is greater and the two objects feel a force of attraction. The effect is most pronounced when the neutral object is an electrical conductor as the charges are more free to move around. Careful grounding of part of an object with a charge-induced charge separation can permanently add or remove electrons, leaving the object with a global, permanent charge. This process is integral to the workings of the Van de Graaff generator, a device commonly used to demonstrate the effects of static electricity.

Electrostatics and Electrodynamics
Static and Current are two ways in which electrical charges can behave. If we said that Electrical Science is divided into two fields of research called Electrostatics and Electrodynamics, we'd be correct.

Michael Faraday first presented a study in 1833 (published in 1839) where he concluded that all the different "forms" of electricity had an identical cause. For the title of this publication he chose... "Identity of Electricities." See vol.1, p360 in his book "Experimental Researches in Electricity".

Faraday examined the following five situations:

1. Voltaic piles (Current Electricity)
2. Electrostatic generators and frictional charge (Static Electricity)
3. Coils and magnetic induction (Current Electricity)
4. Thermoelectricity (Seebeck effect)
5. Bioelectricity ("torpedo" ray and Electric Eel)

Faraday concluded that all these were simply situations where the charge and the current had different values. We believe the same today: for example, so called "static electricity" involves high voltage at little or no current. Are batteries a source of "current electricity?" Well, stack up enough batteries in series, and the ones on the end will attract lint, produce corona discharges, and cause hair to rise. And hook up enough Van de Graaff machines in parallel, and you can light up a standard fluorescent tube.

But suppose you don't trust authorities like Faraday? Well, instead let's examine the situation itself. First, please realize that the study of *water* is divided into Hydrostatics and Hydrodynamics, yet we don't go around constantly discussing a special kind of water called "static water," nor do we think that "current water" is a kind of invisible energy. Water can move, and water can be pressurized, but it's still just one kind of water. The same applies to electric charges.

For those among us who insist that "Static electricity" and "Current electricity" are two separate kinds of electricity, then please explain the following. Whenever positive and negative charges are forced to separate as they flow along a pair of wires, then those wires become electrostatically charged... but the charges are *not static*. Instead they're flowing along.

"Static electricity" is a misnomer. "Static" is actually composed of forcibly *separated* opposite charges, and if those separated charges should flow along, they still behave as "static electricity," regardless of their motion. The key is the separation of the charges...*while their "static-ness" is not important.* For this reason, charges can behave as "static electricity" and "current electricity" both at the same time.

This is not so terrible, since water behaves in a similar way: water can be pressurized, and it can flow at the same time. A flow of high-pressure water simultaneously falls under the two subjects of "hydrostatics" and "hydrodynamics."

Fortunately, we don't confuse students by calling high-pressure water by the name "static water." Maybe we should change the name of "Static electricity" to something sensible, like "charge imbalance", or "pressurized electricity." It would end a lot of confusion.

So to sum up... charges can flow, and opposite charges can be forced to separate and become un-cancelled, but this doesn't mean that "flowing electricity" is a different *kind* of charge than "separated electricity." Separation and flow are two electrical behaviors; they are not two "kinds of electricity."

Flow of Charge

Electric current is not a flow of energy; it's a flow of charge. Charge and energy are two very different things.

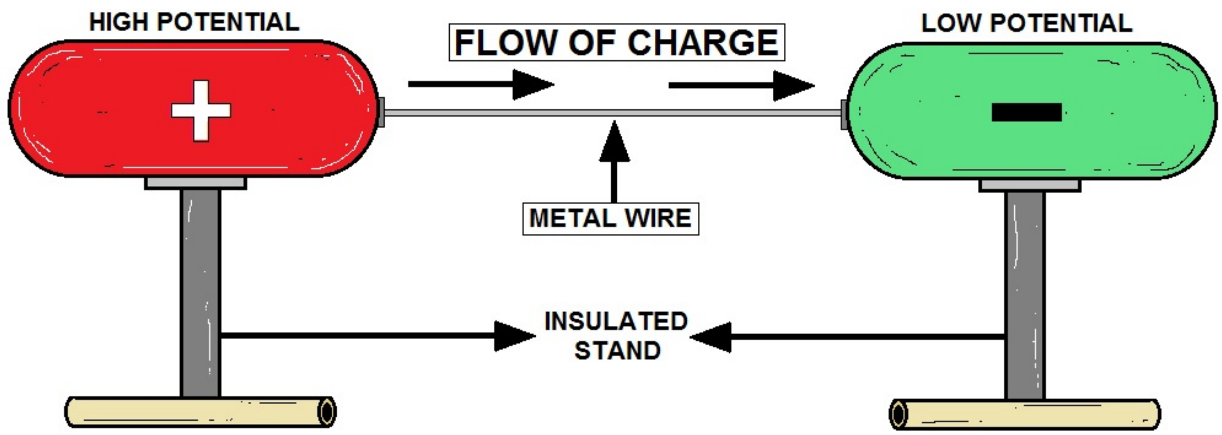
An electric current is a flowing motion of charged particles, and the particles do not carry energy along with them as they move. A current is defined as a flow of charge by I=Q/T; amperes are coulombs of charge flowing per unit time. The term "Electric Current" means the same thing as "charge flow."

Electric current is a very <u>slow</u> flow of charges, while energy flows fast. Also, during AC alternating current the *charges* move slightly back and forth while the *energy* moves rapidly forward.

Electric energy is quite different than charge. The energy traveling across an electric current is made up of waves in electromagnetic fields and it moves VERY rapidly.

Electric energy moves at a completely different speed than electric current, and obviously they are two different things flowing in wires at the same time. Unless we realize that two different things are flowing, we won't understand how circuits work. Indeed, if we believe in a single flowing "electricity," we will have little grasp of basic electrical science.

In an electric circuit, the path of the electric charges is circular, while the path of the energy is not. A battery can send electric energy to a light bulb, and the bulb changes electrical energy into light. The energy does *not* flow back to the battery again. At the same time, the electric current is different; it is a very slow circular flow, and the electric charges flow through the light bulb filament and all of them flow back out again. They return to the battery.



ELECTRICAL CURRENT

Electric energy can even flow in a direction *opposite* to that of the electric current. In a single wire, electric energy can move continuously forward while the direction of the electric current is slowly backwards. In AC circuits the energy flows continuously forward while the charges are alternating back and forth at high frequency. The charges wiggle, while the energy flows forward; electric current is not energy flow.

Here's one way to clarify the muddled concepts: if electric current is like wind, then electrical energy is like some sound waves, and the electrons are like the molecules of the air.

For example, sound can travel through a pipe if the pipe is full of air molecules, and electrical energy can flow along a wire because the wire is full of movable charges.

Sound moves much faster than wind, correct?

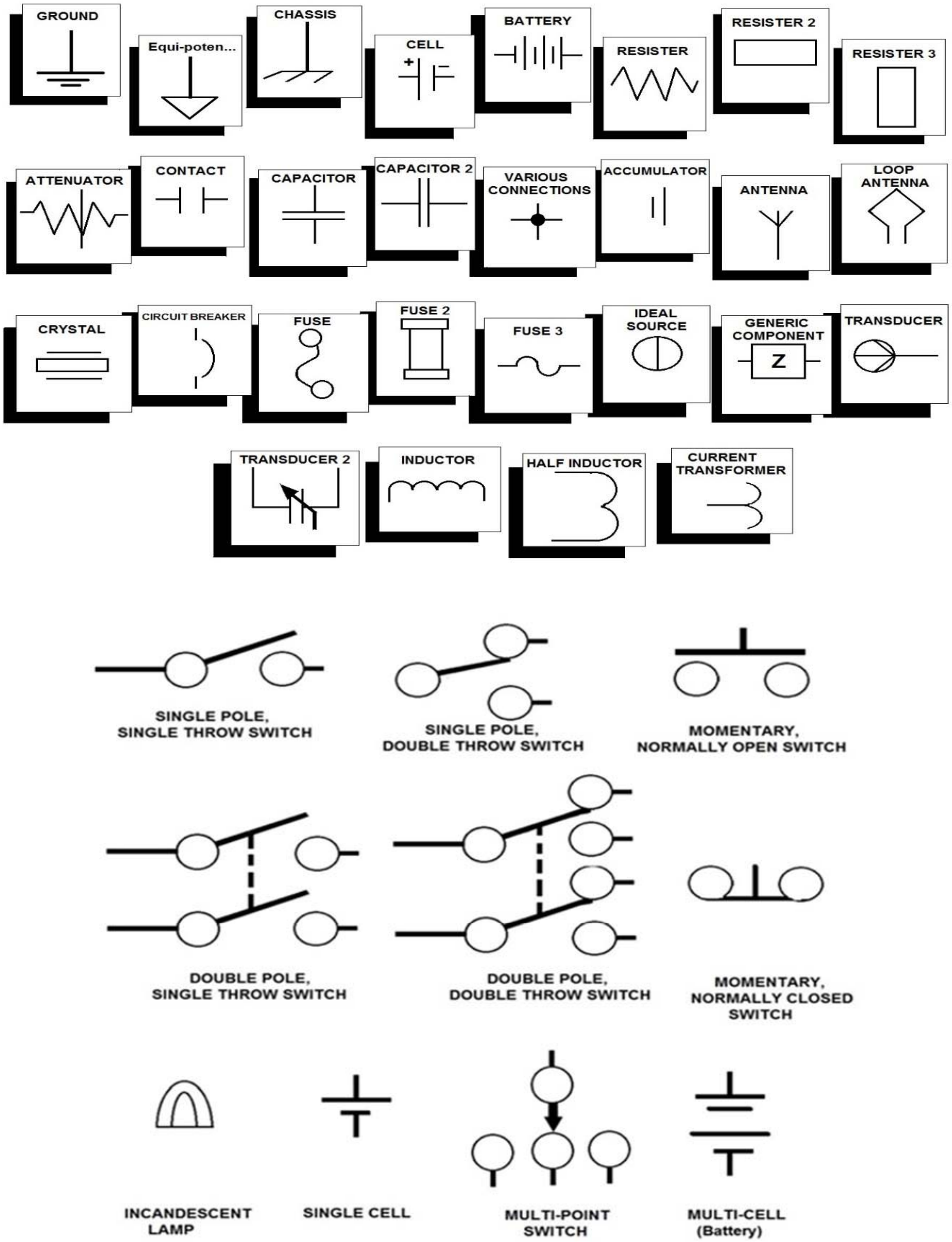
And electrical energy moves much faster than electric current for much the same reason. Air in a pipe can flow fast or slow, while sound waves always move at the same very high speed.

Charges in a wire can flow fast or slow, while electrical energy always flows along the wire at a single incredibly high speed. Whenever sound is flowing through a pipe, the air molecules in that pipe are vibrating back and forth. And when waves of AC electrical energy are flowing along a wire, the electrons in that wire are vibrating back and forth 60 times per second. Sound can flow inside an air-filled tube, while electrical energy always flows in the space outside of the wires, and does not travel along within the metal wires.

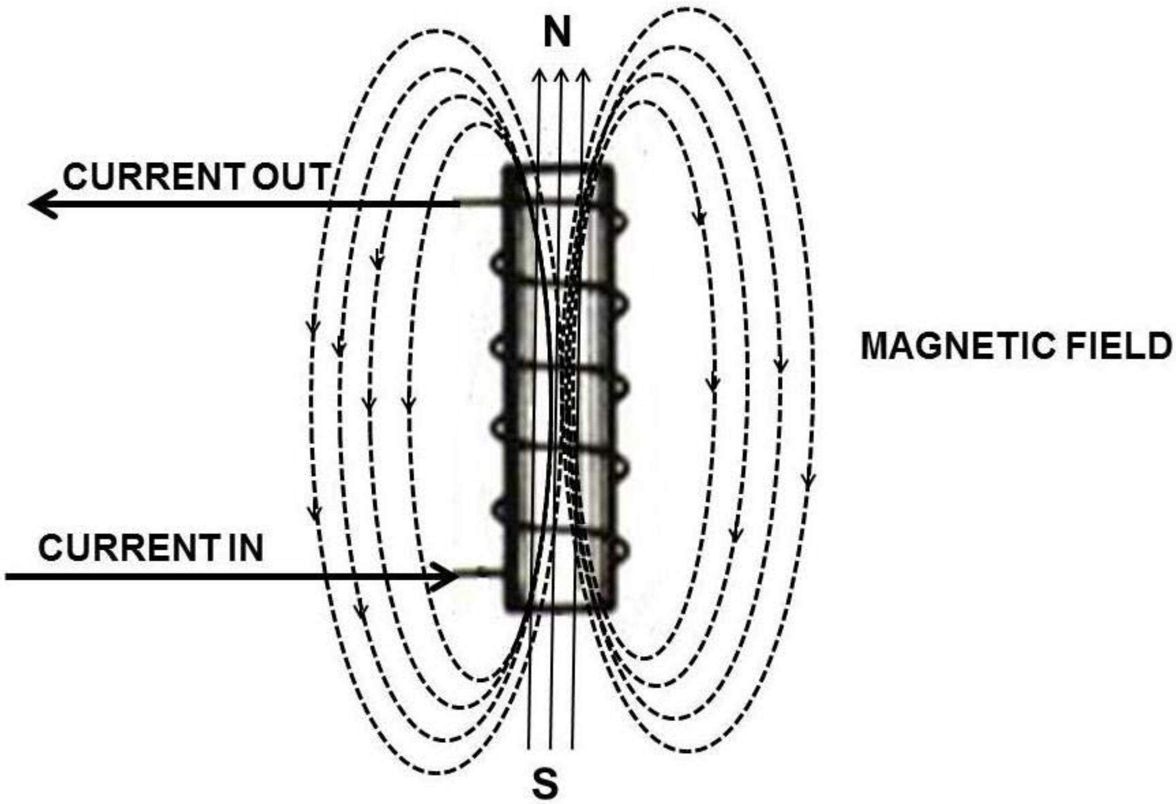
However, electrical energy is coupled with compression waves in the electrons of the wire. Electron-waves travel inside the wires, yet the energy they carry is in the invisible fields surrounding the wires.

ELECTRIC CHARGE	---	**E.M. ENERGY**
Flows very slowly, and can even stop.	-----	Always flows incredibly fast, almost at the speed of light.
The flow is called "electric current," measured in Amps.	-----	The flow is called "electric power," measured in Watts.
Flows through light bulbs	---	Consumed by light bulbs (and converted into light)
In AC cables, it wiggles back and forth	---	In AC cables, it flows continuously forwards
Supplied by metals (and by all other conductors)	---	Supplied by generators, batteries, etc.
It's a component of matter	---	A form of energy
Doesn't usually leave a circuit.	---	A "Source" injects it into a circuit, while a "load" removes it again.
Composed of movable charges from conductor atoms	---	Composed of electromagnetic fields
Electrons and protons are particles of CHARGE	---	Photons are particles of E.M. energy
Flows inside of wires	---	Flows in the space adjacent to wires
Generators pump it through themselves	---	Generators create it
Circular flow. It flows around and around the circuit, and never leaves it.	---	One-way flow, from a "source" to a "load".
VISIBLE: it is the silvery part of a metal	---	INVISIBLE: the EM energy can only be seen if you use iron filings, etc.
Measured in units called Coulombs	---	Measured in units called Joules
Occurs naturally	---	Produced and sold by electric companies
Scientists of old called it "electricity."	---	Today, electric companies call it "electricity."

BASIC ELECTRICAL SYMBOLS



Magnets and Electricity Sub-Section



MAGNETIC FIELD AROUND A BAR MAGNET

The spinning of the electrons around the nucleus of an atom creates a tiny magnetic field. Most objects are not magnetic because their electrons spin in different, random directions, and cancel out each other.

Magnets are different; the molecules in magnets are arranged so that their electrons spin in the same direction. This arrangement of atoms creates two poles in a magnet, a North-seeking pole and a South-seeking pole.

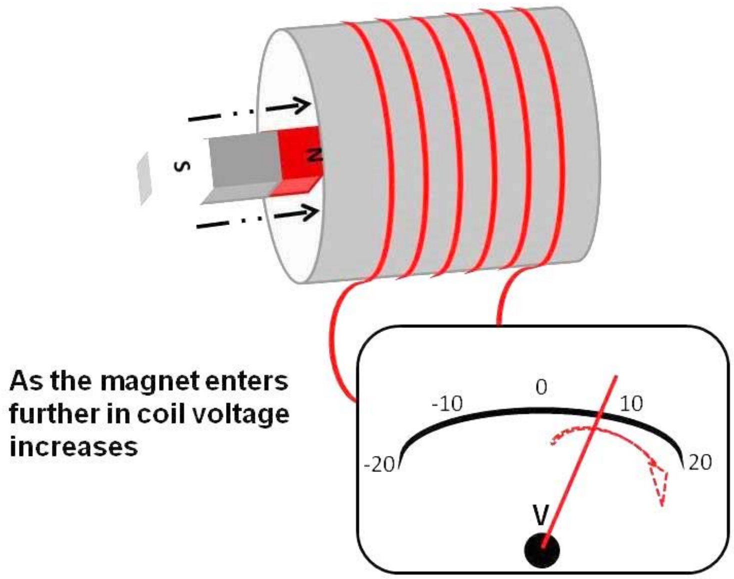
Magnets Have Magnetic Fields

The magnetic force in a magnet flows from the North pole to the South pole. This creates a magnetic field around a magnet. Have you ever held two magnets close to each other?

They don't act like most objects.

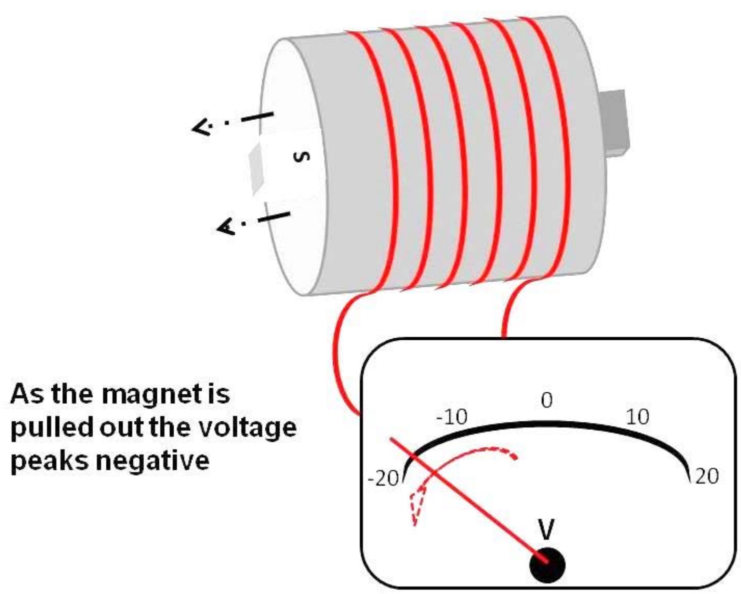
If you try to push the South poles together, they repel each other.

Two North poles also repel each other. Turn one magnet around, and the North (N) and the South (S) poles are attracted to each other. Just like protons and electrons — opposites attract.



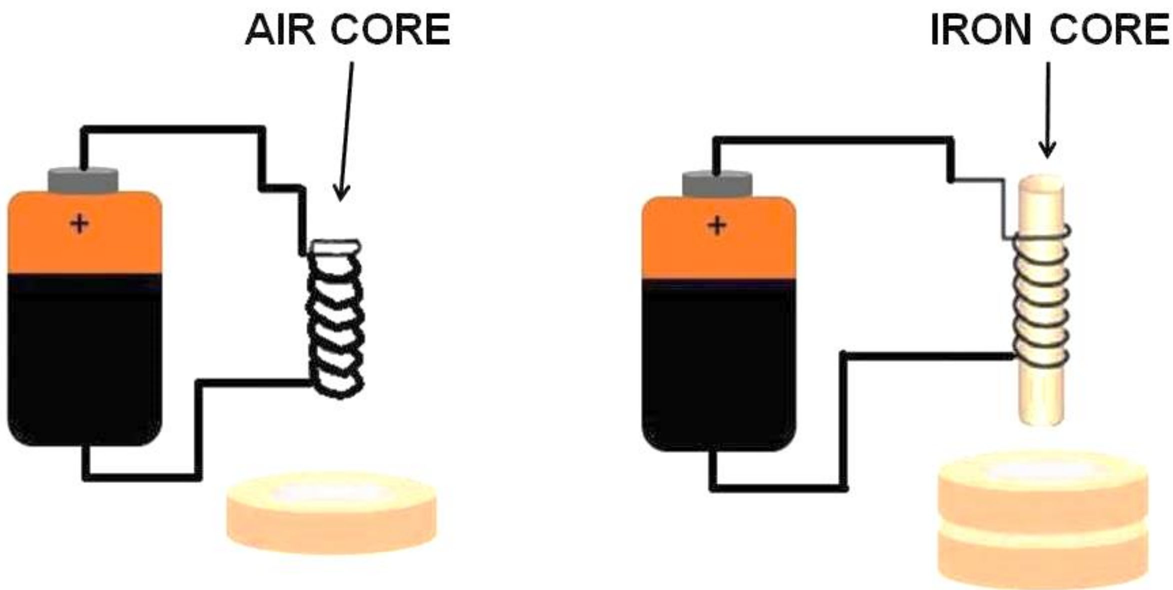
ELECTROMAGNETIC INDUCTION

Magnetic Fields Can Be Used To Make Electricity
Properties of magnets can be used to make electricity. Moving magnetic fields can pull and push electrons. Metals such as copper have electrons that are loosely held. So electrons in copper wires can easily be pushed from their shells by moving magnets. By using moving magnets and copper wire together, electric generators create electricity. Electric generators essentially convert kinetic energy (the energy of motion) into electrical energy.



ELECTROMAGNETIC INDUCTION

Electromagnets and Electromagnetism



ELECTRO-MAGNET DIAGRAM

Magnetic Field Circles around a Current
Ørsted's discovery in 1821 that a magnetic field existed around all sides of a wire carrying an electric current indicated that there was a direct relationship between electricity and magnetism. Moreover, the interaction seemed different from gravitational and electrostatic forces, the two forces of nature then known. The force on the compass needle did not direct it to or away from the current-carrying wire, but acted at right angles to it. Ørsted's slightly obscure words were that "the electric conflict acts in a revolving manner." The force also depended on the direction of the current, for if the flow was reversed, then the force did too.

Ørsted did not fully understand his discovery, but he observed the effect was reciprocal: a current exerts a force on a magnet, and a magnetic field exerts a force on a current. The phenomenon was further investigated by Ampère, who discovered that two parallel current-carrying wires exerted a force upon each other: two wires conducting currents in the same direction are attracted to each other, while wires containing currents in opposite directions are forced apart. The interaction is mediated by the magnetic field each current produces and forms the basis for the international definition of the ampere.

The electric motor exploits an important effect of electromagnetism: a current through a magnetic field experiences a force at right angles to both the field and current.

This relationship between magnetic fields and currents is extremely important, for it led to Michael Faraday's invention of the electric motor in 1821. Faraday's homopolar motor consisted of a permanent magnet sitting in a pool of mercury.

A current was allowed through a wire suspended from a pivot above the magnet and dipped into the mercury. The magnet exerted a tangential force on the wire, making it circle around the magnet for as long as the current was maintained.

Experimentation by Faraday in 1831 revealed that a wire moving perpendicular to a magnetic field developed a potential difference between its ends. Further analysis of this process, known as electromagnetic induction, enabled him to state the principle, now known as Faraday's law of induction, that the potential difference induced in a closed circuit is proportional to the rate of change of magnetic flux through the loop.

Exploitation of this discovery enabled him to invent the first electrical generator in 1831, in which he converted the mechanical energy of a rotating copper disc to electrical energy. Faraday's disc was inefficient and of no use as a practical generator, but it showed the possibility of generating electric power using magnetism, a possibility that would be taken up by those that followed on from his work.

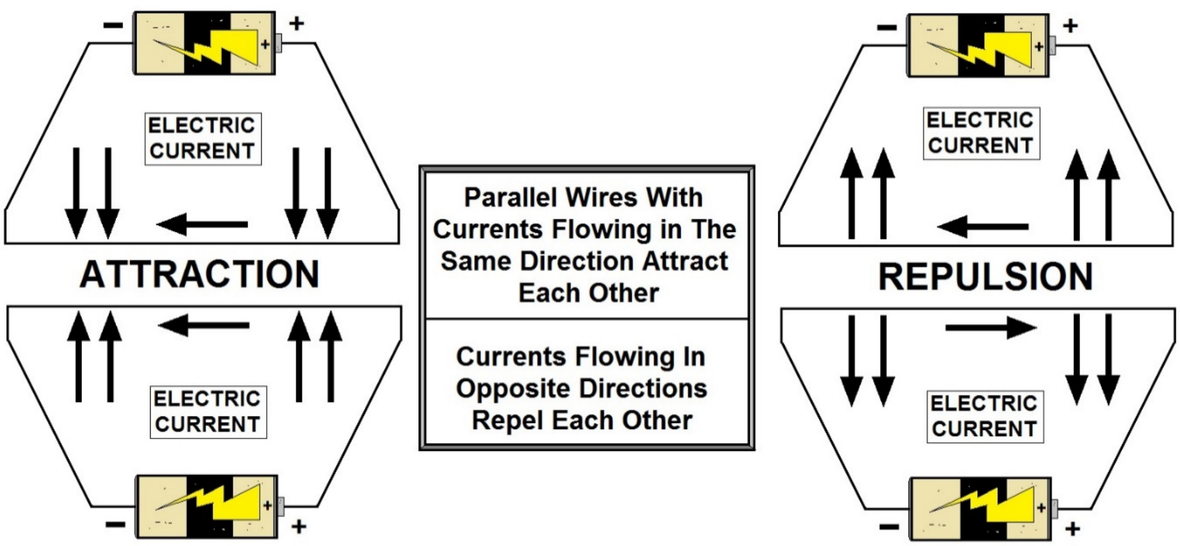
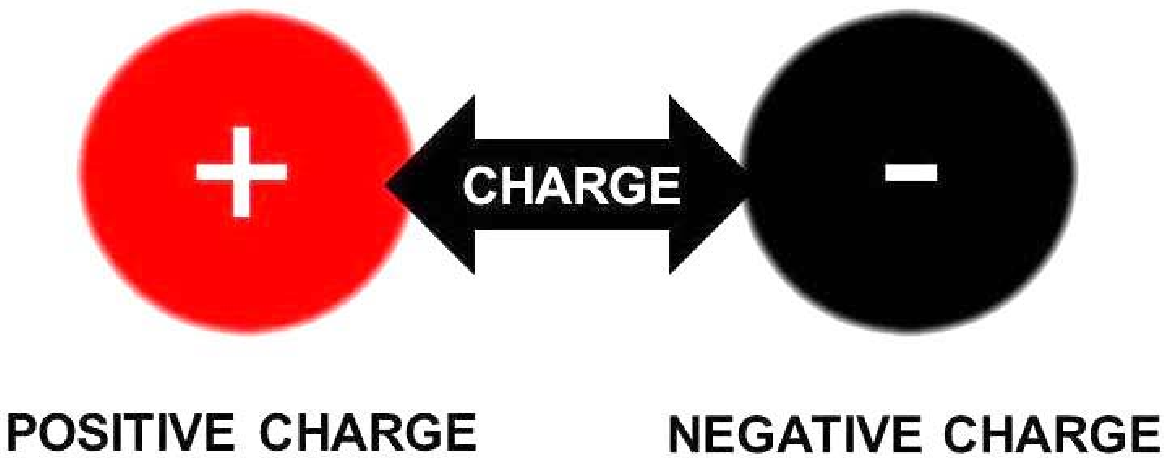


ILLUSTRATION OF AMPÉRE'S DISCOVERY

Understanding the Electric Charge Sub-Section



The presence of charge gives rise to an electrostatic force: charges exert a force on each other, an effect that was known, though not understood, in antiquity. A lightweight ball suspended from a string can be charged by touching it with a glass rod that has itself been charged by rubbing with a cloth. If a similar ball is charged by the same glass rod, it is found to repel the first: the charge acts to force the two balls apart. Two balls that are charged with a rubbed amber rod also repel each other. However, if one ball is charged by the glass rod and the other by an amber rod, the two balls are found to attract each other. These phenomena were investigated in the late eighteenth century by Charles-Augustin de Coulomb, who deduced that charge manifests itself in two opposing forms. This discovery led to the well-known axiom: like-charged objects repel and opposite-charged objects attract.

The force acts on the charged particles themselves, hence charge has a tendency to spread itself as evenly as possible over a conducting surface. The magnitude of the electromagnetic force, whether attractive or repulsive, is given by Coulomb's law, which relates the force to the product of the charges and has an inverse-square relation to the distance between them. The electromagnetic force is very strong, second only in strength to the strong interaction, but unlike that force it operates over all distances. In comparison with the much weaker gravitational force, the electromagnetic force pushing two electrons apart is 10^{42} (10 to the 42 power) times that of the gravitational attraction pulling them together.

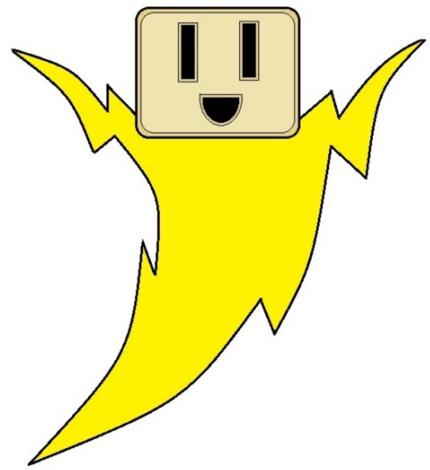
Study has shown that the origin of charge is from certain types of subatomic particles which have the property of electric charge. Electric charge gives rise to and interacts with the electromagnetic force, one of the four fundamental forces of nature. The most familiar carriers of electrical charge are the electron and proton.

Experiment has shown charge to be a conserved quantity, that is, the net charge within an isolated system will always remain constant regardless of any changes taking place within that system. Within the system, charge may be transferred between bodies, either by direct contact, or by passing along a conducting material, such as a wire. The informal term static electricity refers to the net presence (or 'imbalance') of charge on a body, usually caused when dissimilar materials are rubbed together, transferring charge from one to the other.

Electric Current Described

The movement of electric charge is known as an electric current, the intensity of which is usually measured in amperes. Current can consist of any moving charged particles; most commonly these are electrons, but any charge in motion constitutes a current.

By historical convention, a positive current is defined as having the same direction of flow as any positive charge it contains, or to flow from the most positive part of a circuit to the most negative part.



Current defined in this manner is called conventional current. The motion of negatively charged electrons around an electric circuit, one of the most familiar forms of current, is thus deemed positive in the opposite direction to that of the electrons.

However, depending on the conditions, an electric current can consist of a flow of charged particles in either direction, or even in both directions at once. The positive-to-negative convention is widely used to simplify this situation.

The process by which electric current passes through a material is termed electrical conduction, and its nature varies with that of the charged particles and the material through which they are travelling.

Examples of electric currents include metallic conduction, where electrons flow through a conductor such as metal, and electrolysis, where ions (charged atoms) flow through liquids, or through plasmas such as electrical sparks. While the particles themselves can move quite slowly, sometimes with an average drift velocity only fractions of a millimeter per second, the electric field that drives them itself propagates at close to the speed of light, enabling electrical signals to pass rapidly along wires.

Current causes several observable effects, which historically were the means of recognizing its presence. That water could be decomposed by the current from a voltaic pile was discovered by Nicholson and Carlisle in 1800, a process now known as electrolysis. Their work was greatly expanded upon by Michael Faraday in 1833. Current through a resistance causes localized heating, an effect James Prescott Joule studied mathematically in 1840.

One of the most important discoveries relating to current was made accidentally by Hans Christian Ørsted in 1820, when, while preparing a lecture, he witnessed the current in a wire disturbing the needle of a magnetic compass. He had discovered electromagnetism, a fundamental interaction between electricity and magnetics.

The level of electromagnetic emissions generated by electric arcing is high enough to produce electromagnetic interference, which can be detrimental to the workings of adjacent equipment.

Electric Shock

Electric shock occurs upon contact of a (human) body part with any source of electricity that causes a sufficient current through the skin, muscles, or hair. Typically, the expression is used to describe an injurious exposure to electricity.

Very small currents can be imperceptible. Larger current passing through the body may make it impossible for a shock victim to let go of an energized object. Still larger currents can cause fibrillation of the heart and damage to tissues. Death caused by an electric shock is called electrocution. Wiring or other metalwork which is at a hazardous voltage which can constitute a risk of electric shock is called "live", as in "live wire".

Magnitude

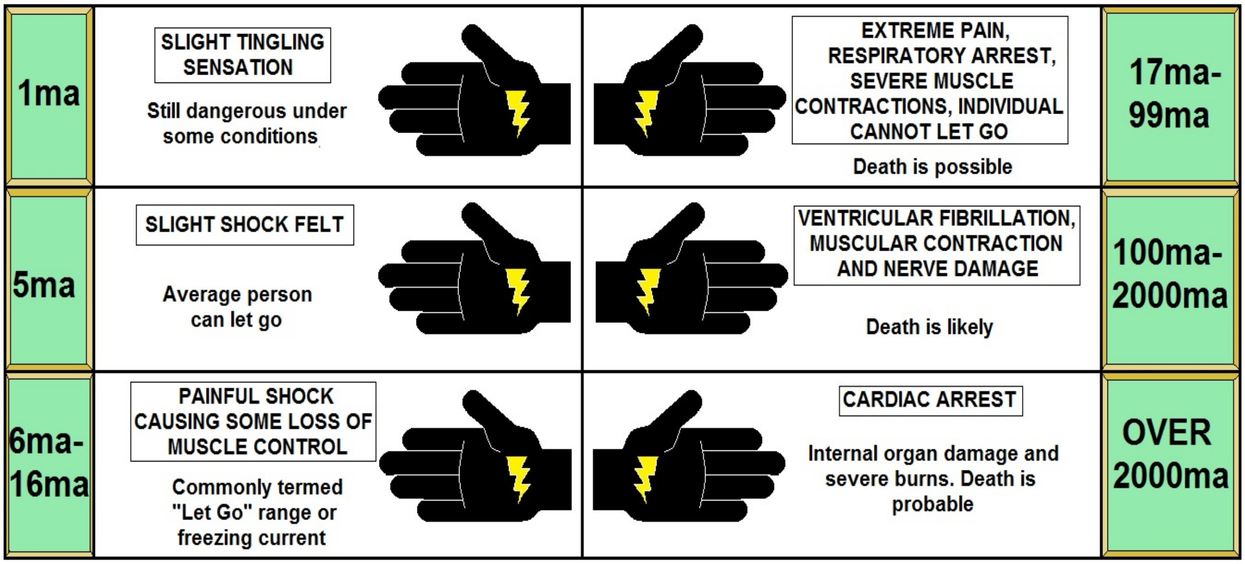
The minimum current a human can feel depends on the current type (AC or DC) and frequency. A person can feel at least 1 mA (rms) of AC at 60 Hz, while at least 5 mA for DC. At around 10 milliamperes, AC current passing through the arm of a 68 kg (150 lb) human can cause powerful muscle contractions; the victim is unable to voluntarily control muscles and cannot release an electrified object. This is known as the "let go threshold" and is a criterion for shock hazard in electrical regulations.

The current may, if it is high enough, cause tissue damage or fibrillation which leads to cardiac arrest; more than 30 mA of AC (rms, 60 Hz) or 300 – 500 mA of DC can cause fibrillation.

A sustained electric shock from AC at 120 V, 60 Hz is an especially dangerous source of ventricular fibrillation because it usually exceeds the let-go threshold, while not delivering enough initial energy to propel the person away from the source. However, the potential seriousness of the shock depends on paths through the body that the currents take.

If the voltage is less than 200 V, then the human skin, more precisely the stratum corneum, is the main contributor to the impedance of the body in the case of a macroshock—the passing of current between two contact points on the skin. The characteristics of the skin are non-linear however. If the voltage is above 450–600 V, then dielectric breakdown of the skin occurs. The protection offered by the skin is lowered by perspiration, and this is accelerated if electricity causes muscles to contract above the let-go threshold for a sustained period of time.

If an electrical circuit is established by electrodes introduced in the body, bypassing the skin, then the potential for lethality is much higher if a circuit through the heart is established. This is known as a microshock. Currents of only 10 μA can be sufficient to cause fibrillation in this case.



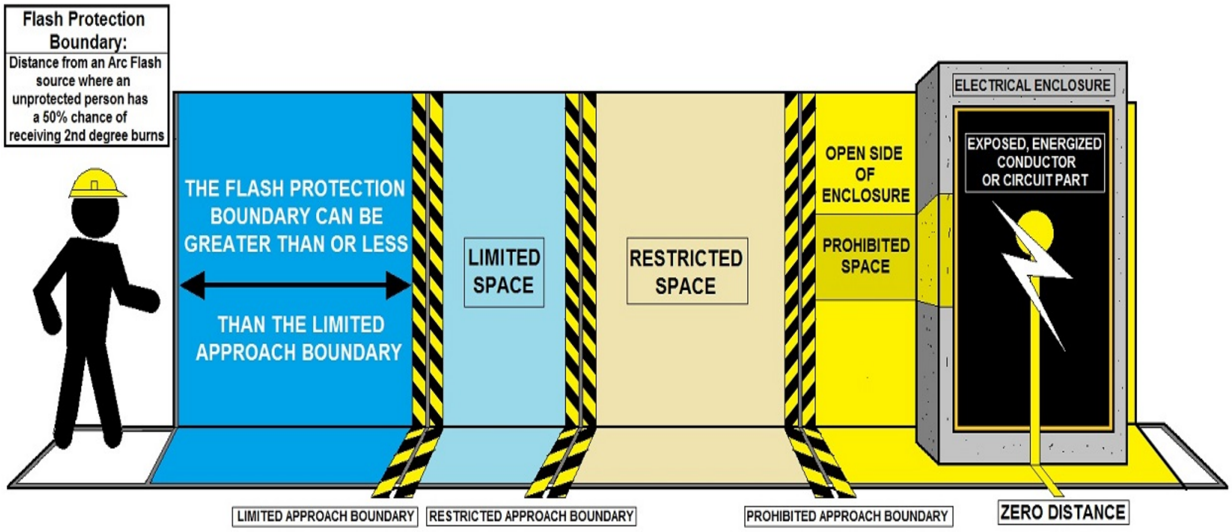
ELECTRICAL SHOCK EFFECTS ON THE HUMAN BODY

EFFECTS OF ELECTRICAL SHOCK

Signs and Symptoms
Burns
Heating due to resistance can cause extensive and deep burns. Voltage levels of 500 to 1000 volts tend to cause internal burns due to the large energy (which is proportional to the duration multiplied by the square of the voltage divided by resistance) available from the source. Damage due to current is through tissue heating.

For most cases of high-energy electrical trauma, the Joule heating in the deeper tissues along the extremity will reach damaging temperatures in a few seconds.

Arc-flash Hazards



ARC FLASH BOUNDARIES EXAMPLE

The arc flash in an electrical fault produces the same type of light radiation from which electric welders protect themselves using face shields with dark glass, heavy leather gloves, and full-coverage clothing. The heat produced may cause severe burns, especially on unprotected flesh. The *arc blast* produced by vaporizing metallic components can break bones and damage internal organs. The degree of hazard present at a particular location can be determined by a detailed analysis of the electrical system, and appropriate protection worn if the electrical work must be performed with the electricity on.

Body Resistance
The voltage necessary for electrocution depends on the current through the body and the duration of the current. Ohm's law states that the current drawn depends on the resistance of the body.

The resistance of human skin varies from person to person and fluctuates between different times of day. The NIOSH states "Under dry conditions, the resistance offered by the human body may be as high as 100,000 Ohms. Wet or broken skin may drop the body's resistance to 1,000 Ohms," adding that "high-voltage electrical energy quickly breaks down human skin, reducing the human body's resistance to 500 Ohms."

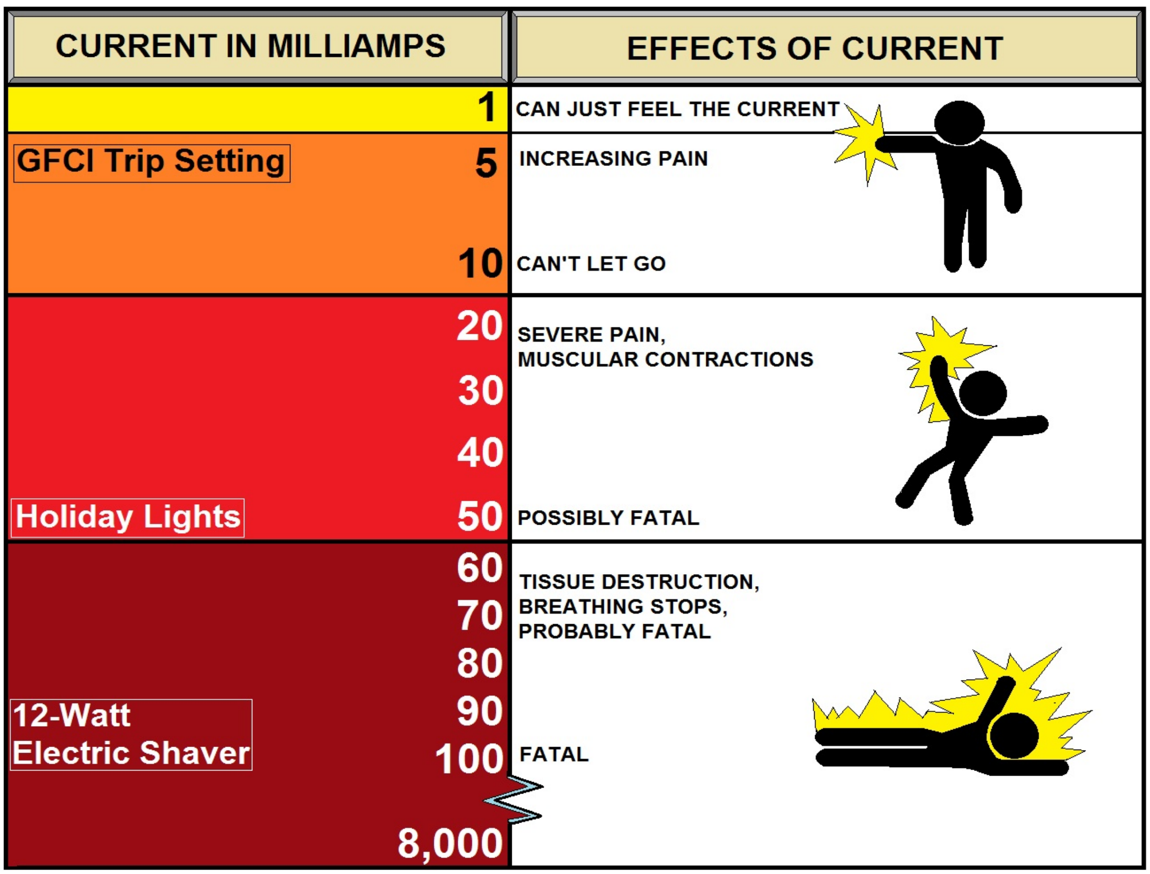
Point of Entry
- **Macroshock**: Current across intact skin and through the body. Current from arm to arm, or between an arm and a foot, is likely to traverse the heart, therefore it is much more dangerous than current between a leg and the ground. This type of shock by definition must pass into the body through the skin.

- **Microshock:** Very small current source with a pathway directly connected to the heart tissue. The shock is required to be administered from inside the skin, directly to the heart i.e. a pacemaker lead, or a guide wire, conductive catheter etc. connected to a source of current. This is a largely theoretical hazard as modern devices used in these situations include protections against such currents.

Electrocution

The term "electrocution," coined about the time of the first use of the electric chair in 1890, originally referred only to **electr**ical exe**cution** (from which it is a portmanteau word), and not to accidental or suicidal electrical deaths.

However, since no English word was available for non-judicial deaths due to electric shock, the word "electrocution" eventually took over as a description of all circumstances of electrical death from the new commercial electricity. The word is often used incorrectly as a synonym of electric shock.



THE EFFECTS OF ELECTRICITY AND THE HUMAN BODY

History of Electromagnetic Theory

Originally electricity and magnetism were thought of as two separate forces. This view changed, however, with the publication of James Clerk Maxwell's 1873 *Treatise on Electricity and Magnetism* in which the interactions of positive and negative charges were shown to be regulated by one force. There are four main effects resulting from these interactions, all of which have been clearly demonstrated by experiments:

1. Electric charges attract or repel one another with a force inversely proportional to the square of the distance between them: unlike charges attract, like ones repel.
2. Magnetic poles (or states of polarization at individual points) attract or repel one another in a similar way and always come in pairs: every north pole is yoked to a south pole.
3. An electric current in a wire creates a circular magnetic field around the wire, its direction (clockwise or counter-clockwise) depending on that of the current.
4. A current is induced in a loop of wire when it is moved towards or away from a magnetic field, or a magnet is moved towards or away from it, the direction of current depending on that of the movement.

While preparing for an evening lecture on 21 April 1820, Hans Christian Ørsted made a surprising observation. As he was setting up his materials, he noticed a compass needle deflected from magnetic north when the electric current from the battery he was using was switched on and off. This deflection convinced him that magnetic fields radiate from all sides of a wire carrying an electric current, just as light and heat do, and that it confirmed a direct relationship between electricity and magnetism.

At the time of discovery, Ørsted did not suggest any satisfactory explanation of the phenomenon, nor did he try to represent the phenomenon in a mathematical framework. However, three months later he began more intensive investigations. Soon thereafter he published his findings, proving that an electric current produces a magnetic field as it flows through a wire. The CGS unit of magnetic induction (Ørsted) is named in honor of his contributions to the field of electromagnetism.

His findings resulted in intensive research throughout the scientific community in electrodynamics. They influenced French physicist André-Marie Ampère's developments of a single mathematical form to represent the magnetic forces between current-carrying conductors. Ørsted's discovery also represented a major step toward a unified concept of energy.

This unification, which was observed by Michael Faraday, extended by James Clerk Maxwell, and partially reformulated by Oliver Heaviside and Heinrich Hertz, is one of the key accomplishments of 19th century mathematical physics. It had far-reaching consequences, one of which was the understanding of the nature of light.

Unlike what was proposed in Electromagnetism, light and other electromagnetic waves are at the present seen as taking the form of quantized, self-propagating oscillatory electromagnetic field disturbances which have been called photons. Different frequencies of oscillation give rise to the different forms of electromagnetic radiation, from radio waves at the lowest frequencies, to visible light at intermediate frequencies, to gamma rays at the highest frequencies.

Ørsted was not the only person to examine the relation between electricity and magnetism. In 1802 Gian Domenico Romagnosi, an Italian legal scholar, deflected a magnetic needle by electrostatic charges. Actually, no galvanic current existed in the setup and hence no electromagnetism was present. An account of the discovery was published in 1802 in an Italian newspaper, but it was largely overlooked by the contemporary scientific community.

Overview

The electromagnetic force is one of the four known fundamental forces. The other fundamental forces are:

- the weak nuclear force, which binds to all known particles in the Standard Model, and causes certain forms of radioactive decay. (In particle physics though, the electroweak interaction is the unified description of two of the four known fundamental interactions of nature: electromagnetism and the weak interaction);
- the strong nuclear force, which binds quarks to form nucleons, and binds nucleons to form nuclei
- the gravitational force.

All other forces (e.g., friction) are ultimately derived from these fundamental forces and momentum carried by the movement of particles.

The electromagnetic force is the one responsible for practically all the phenomena one encounters in daily life above the nuclear scale, with the exception of gravity. Roughly speaking, all the forces involved in interactions between atoms can be explained by the electromagnetic force acting on the electrically charged atomic nuclei and electrons inside and around the atoms, together with how these particles carry momentum by their movement. This includes the forces we experience in "pushing" or "pulling" ordinary material objects, which come from the intermolecular forces between the individual molecules in our bodies and those in the objects. It also includes all forms of chemical phenomena.

A necessary part of understanding the intra-atomic to intermolecular forces is the effective force generated by the momentum of the electrons' movement, and that electrons move between interacting atoms, carrying momentum with them. As a collection of electrons becomes more confined, their minimum momentum necessarily increases due to the Pauli exclusion principle. The behavior of matter at the molecular scale including its density is determined by the balance between the electromagnetic force and the force generated by the exchange of momentum carried by the electrons themselves.

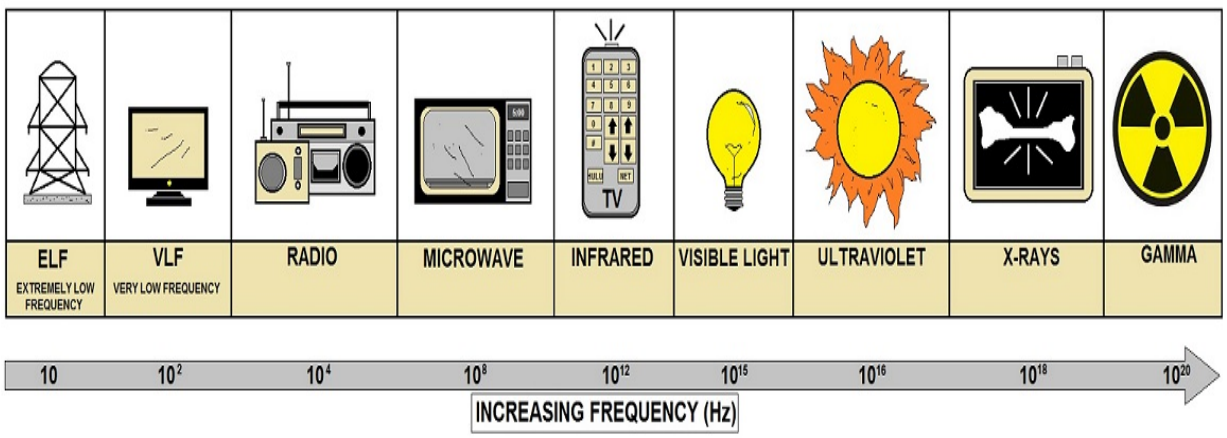
Classical Electrodynamics

The scientist William Gilbert proposed, in his *De Magnete* (1600), that electricity and magnetism, while both capable of causing attraction and repulsion of objects, were distinct effects. Mariners had noticed that lightning strikes had the ability to disturb a compass needle, but the link between lightning and electricity was not confirmed until Benjamin Franklin's proposed experiments in 1752. One of the first to discover and publish a link between man-made electric current and magnetism was Romagnosi, who in 1802 noticed that connecting a wire across a voltaic pile deflected a nearby compass needle.

However, the effect did not become widely known until 1820, when Ørsted performed a similar experiment. Ørsted's work influenced Ampère to produce a theory of electromagnetism that set the subject on a mathematical foundation.

A theory of electromagnetism, known as classical electromagnetism, was developed by various physicists over the course of the 19th century, culminating in the work of James Clerk Maxwell, who unified the preceding developments into a single theory and discovered the electromagnetic nature of light. In classical electromagnetism, the j obeys a set of equations known as Maxwell's equations, and the electromagnetic force is given by the Lorentz force law.

One of the peculiarities of classical electromagnetism is that it is difficult to reconcile with classical mechanics, but it is compatible with special relativity. According to Maxwell's equations, the speed of light in a vacuum is a universal constant, dependent only on the electrical permittivity and magnetic permeability of free space.



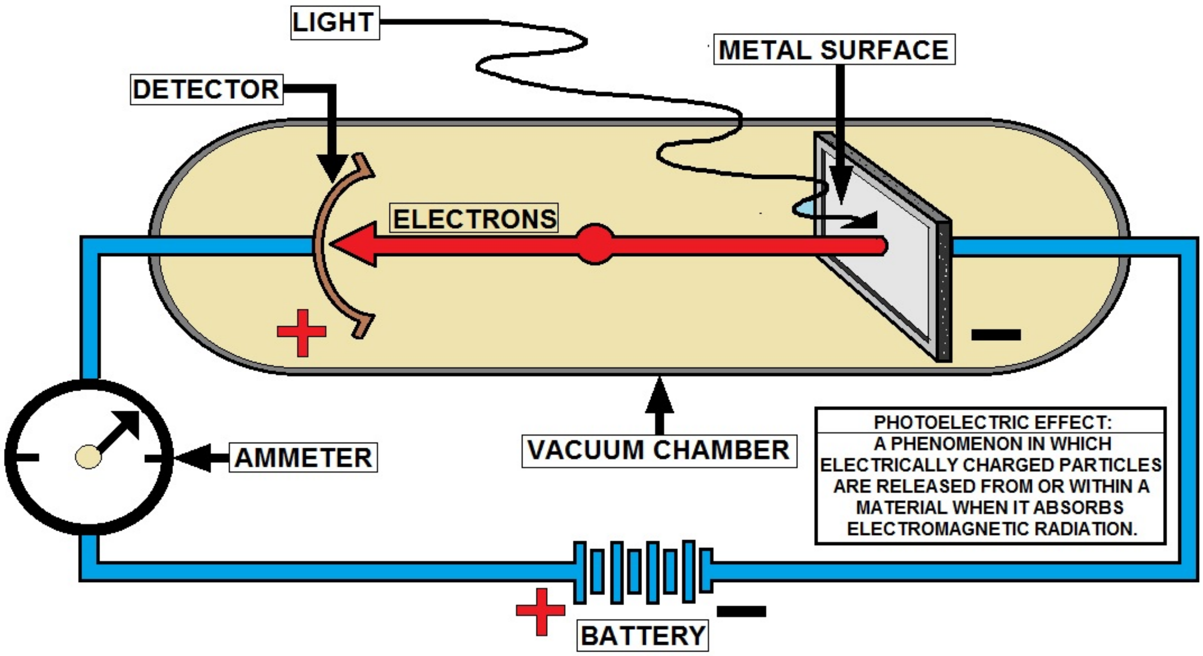
ELECTROMAGNETIC FIELD EXAMPLES

This violates Galilean invariance, a long-standing cornerstone of classical mechanics. One way to reconcile the two theories (electromagnetism and classical mechanics) is to assume the existence of a luminiferous aether through which the light propagates. However, subsequent experimental efforts failed to detect the presence of the aether.

After important contributions of Hendrik Lorentz and Henri Poincaré, in 1905, Albert Einstein solved the problem with the introduction of special relativity, which replaces classical kinematics with a new theory of kinematics that is compatible with classical electromagnetism.

In addition, relativity theory shows that in moving frames of reference a magnetic field transforms to a field with a nonzero electric component and vice versa; thus firmly showing that they are two sides of the same coin, and thus the term "electromagnetism".

Photoelectric Effect
In another paper published in that same year, Albert Einstein undermined the very foundations of classical electromagnetism. In his theory of the photoelectric effect (for which he won the Nobel prize for physics) and inspired by the idea of Max Planck's "quanta", he posited that light could exist in discrete particle-like quantities as well, which later came to be known as photons.



PHOTOELECTRIC EFFECT

Einstein's theory of the photoelectric effect extended the insights that appeared in the solution of the ultraviolet catastrophe presented by Max Planck in 1900.

In his work, Planck showed that hot objects emit electromagnetic radiation in discrete packets ("quanta"), which leads to a finite total energy emitted as black body radiation. Both of these results were in direct contradiction with the classical view of light as a continuous wave.

Planck's and Einstein's theories were progenitors of quantum mechanics, which, when formulated in 1925, necessitated the invention of a quantum theory of electromagnetism.

This theory, completed in the 1940s-1950s, is known as quantum electrodynamics (or "QED"), and, in situations where perturbation theory is applicable, is one of the most accurate theories known to physics.

Quantities and Units

Electromagnetic units are part of a system of electrical units based primarily upon the magnetic properties of electric currents, the fundamental SI unit being the ampere. The units are:

- ampere (electric current)
- coulomb (electric charge)
- farad (capacitance)
- henry (inductance)
- ohm (resistance)
- tesla (magnetic flux density)
- volt (electric potential)
- watt (power)
- weber (magnetic flux

SI Electromagnetism Units

Symbol	Name of Quantity	Derived Units	Unit	Base Units
I	electric current	ampere (SI base unit)	A	A (= W/V = C/s)
Q	electric charge	coulomb	C	A·s
U, Δ*V*, Δ*φ*; *E*	potential difference; electromotive force	volt	V	$kg·m^2·s^{-3}·A^{-1}$ (= J/C)
R; *Z*; *X*	electric resistance; impedance; reactance	ohm	Ω	$kg·m^2·s^{-3}·A^{-2}$ (= V/A)
ρ	resistivity	ohm meter	Ω·m	$kg·m^3·s^{-3}·A^{-2}$
P	electric power	watt	W	$kg·m^2·s^{-3}$ (= V·A)
C	capacitance	farad	F	$kg^{-1}·m^{-2}·s^4·A^2$ (= C/V)
E	electric field strength	volt per meter	V/m	$kg·m·s^{-3}·A^{-1}$ (= N/C)
D	electric displacement field	coulomb per square meter	C/m^2	$A·s·m^{-2}$
ε	permittivity	farad per meter	F/m	$kg^{-1}·m^{-3}·s^4·A^2$
χ_e	electric susceptibility	(dimensionless)	–	–
G; *Y*; *B*	conductance; admittance; susceptance	siemens	S	$kg^{-1}·m^{-2}·s^3·A^2$ (= $Ω^{-1}$)
κ, *γ*, *σ*	conductivity	siemens per meter	S/m	$kg^{-1}·m^{-3}·s^3·A^2$
B	magnetic flux density, magnetic induction	tesla	T	$kg·s^{-2}·A^{-1}$ (= Wb/m^2 = $N·A^{-1}·m^{-1}$)
Φ	magnetic flux	weber	Wb	$kg·m^2·s^{-2}·A^{-1}$ (= V·s)
H	magnetic field strength	ampere per meter	A/m	$A·m^{-1}$
L, *M*	inductance	henry	H	$kg·m^2·s^{-2}·A^{-2}$ (= Wb/A = V·s/A)
μ	permeability	henry per meter	H/m	$kg·m·s^{-2}·A^{-2}$
χ	magnetic susceptibility	(dimensionless)	–	–

Formulas for physical laws of electromagnetism (such as Maxwell's equations) need to be adjusted depending on what system of units one uses. This is because there is no one-to-one correspondence between electromagnetic units in SI and those in CGS, as is the case for mechanical units.

Furthermore, within CGS, there are several plausible choices of electromagnetic units, leading to different unit "sub-systems", including Gaussian, "ESU", "EMU", and Heaviside–Lorentz. Among these choices, Gaussian units are the most common today, and in fact the phrase "CGS units" is often used to refer specifically to CGS-Gaussian units.

Section 2 – Simple Forms of Electricity Post Quiz

1. Which term is the main cause of static electricity as observed in everyday life?

2. Which term can be exchanged between materials on contact?

3. Which term causes your hair to stand up and causes static cling?

Pressure-induced Charge Separation

4. Which term causes a separation of charge in certain types of crystals and ceramics molecules?

Heat-induced Charge Separation

5. Heating does not generate separation of charges of atoms or molecules of certain materials.
A. True B. False

6. The atomic or molecular properties of force and pressure response are closely related.
A. True B. False

7. All pyroelectric materials are also?

Electromagnets and Electromagnetism
Magnetic field circles around a current

8. Magnetic fields exist around all sides of a wire carrying an electric current and there is a direct relationship between electricity and magnetism.
A. True B. False

9. In Ørsted's experiments, the force on the compass needle did not direct it to or away from the current-carrying wire, but acted at right angles to it.
A. True B. False

10. The force was not dependent on the direction of the current, for if the flow was reversed, then the force remained the same.
A. True B. False

Section 2 – Post Quiz Answers

1. The triboelectric effect
2. Electron(s)
3. Contact-induced charge separation
4. Applied mechanical stress
5. False
6. False
7. Piezoelectric
8. True
9. True
10. False

Section 3 – Electrical Principles and Application Introduction

Section Focus: You will learn the basics of electrical principles, distribution and terminology. At the end of this section, you will be able to understand and describe simple forms of electrical principles and distribution. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: In order to understand electrical principles, we first need to explain the various simple forms of electricity. Because this area of study is quite large and detailed, we will only focus upon electrical power and voltage.

What is Electric Power?

Electric power is the rate at which electric energy is transferred by an electric circuit. The SI unit of power is the watt, one joule per second.

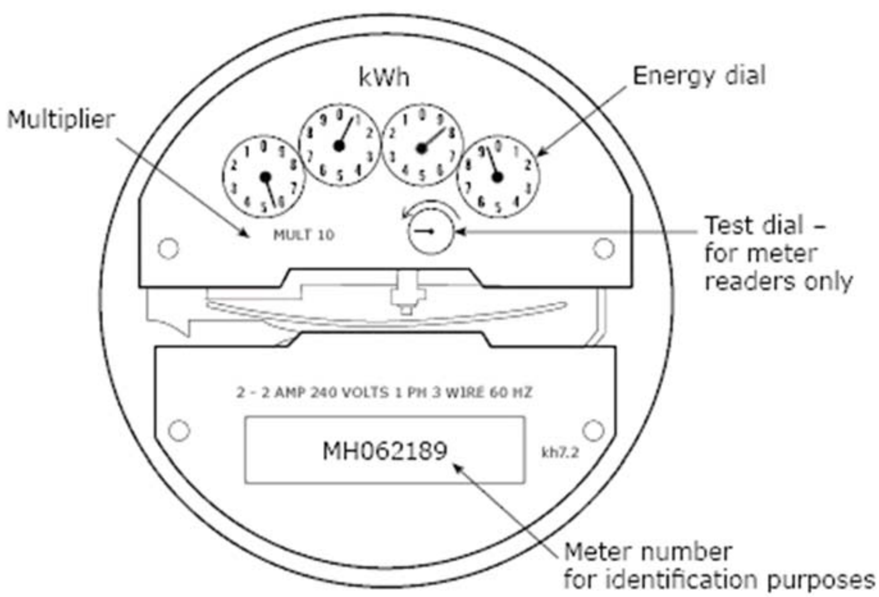
Electric power, like mechanical power, is the rate of doing work, measured in watts, and represented by the letter *P*.

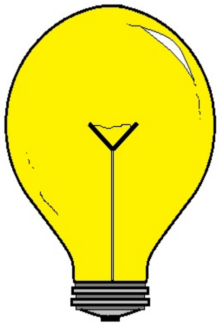
The term *wattage* is used colloquially to mean "electric power in watts." The electric power in watts produced by an electric current *I* consisting of a charge of *Q* coulombs every *t* seconds passing through an electric potential (voltage) difference of *V* is

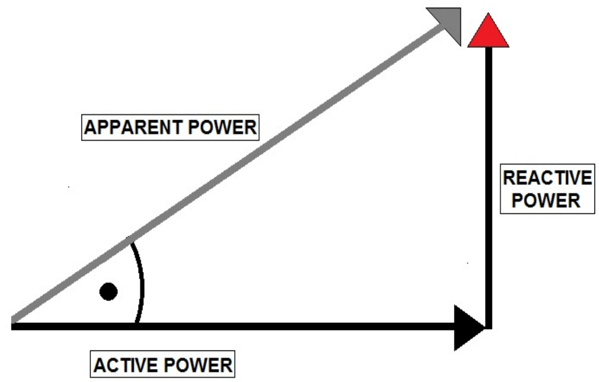
$$P = \text{work done per unit time} = \frac{QV}{t} = IV$$

where

Q is electric charge in coulombs
t is time in seconds
I is electric current in amperes
V is electric potential or voltage in volts







ELECTRICAL ENERGY IS ENERGY DERIVED AS A RESULT OF MOVEMENT OF ELECTRONS. WHEN USED LOOSELY, ELECTRICAL ENERGY REFERS TO THAT HAS BEEN CONVERTED FROM ELECTRIC POTENTIAL ENERGY

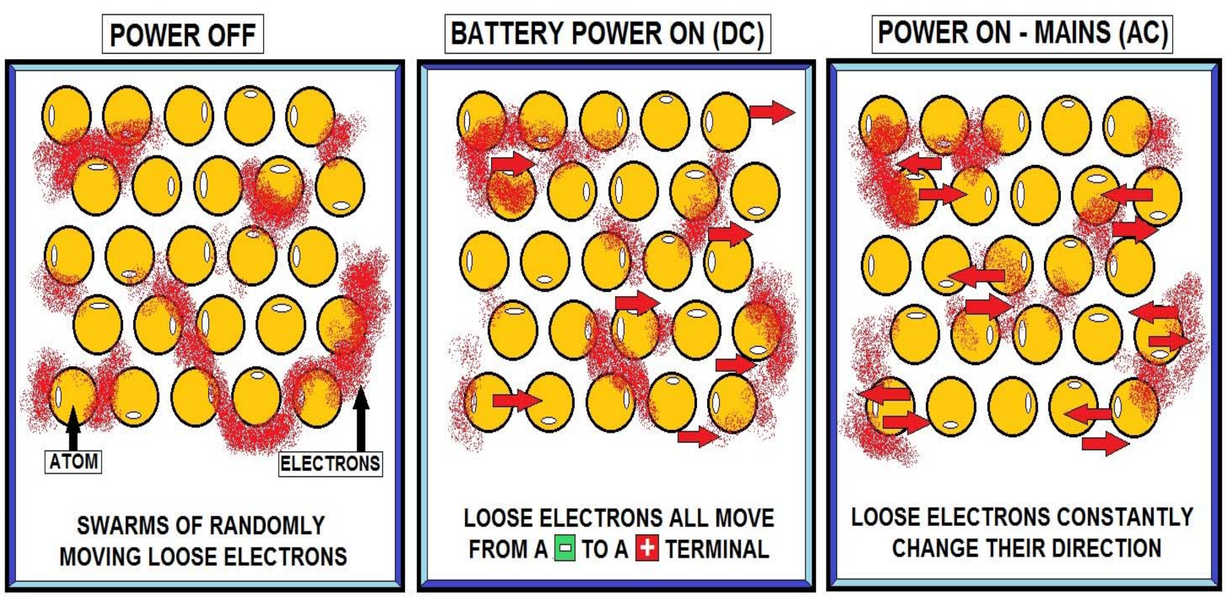
ELECTRIC POWER IS THE RATE, PER UNIT TIME, AT WHICH ELECTRICAL ENERGY IS TRANSFERRED BY AN ELECTRIC UNIT

DIFFERENCE BETTWEN ELECTRICAL ENERGY AND ELECTRICAL POWER

Electricity generation is often done with electric generators, but can also be supplied by chemical sources such as electric batteries or by other means from a wide variety of sources of energy.

Electric power is generally supplied to businesses and homes by the electric power industry.

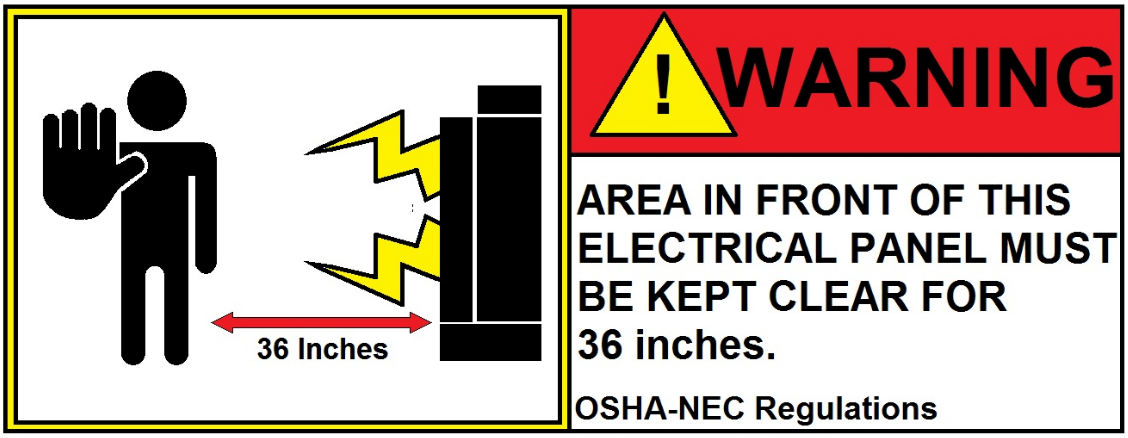
Electricity is usually sold by the kilowatt hour (3.6 MJ) which is the product of power in kilowatts multiplied by running time in hours. Electric utilities measure power using electricity meters, which keep a running total of the electric energy delivered to a customer.



BASIC EXAMPLE OF WHAT OCCURS IN ELECTRICAL WIRES

Safety First- Reminder

Hidden Dangers of Electricity and Electrical Components
There are some projects that are much more dangerous to work on like electrical meters, disconnects and panels. If you are not comfortable working with electrical circuits or are just unsure of your electrical knowledge, some of these tougher projects should be left to the professionals. After all, they are specifically trained to work with household voltages, not to mention commercial and industrial application voltages.



ELECTRICAL PANEL WARNING LABEL

The First Step to Electrical Safety is Turning Off the Power
First, always turn off the power to the circuit that you'll be working on at the main service panel or disconnect feeding the circuit that you are going to be working on. Remember, no power to the circuit means that you are safe to proceed to work on that circuit or device connected to it. But, how do I know the circuit is off for sure?

Electrical Testers and Testing
That brings me to my next step, testing. You should always test devices, panels; etc… before touching anything to make sure it is off. A non-contact voltage tester can detect if the circuit is on before you ever take a switch or outlet out of the box and expose any wires. Simply take off the cover and hold it next to the device. Some of these testers require you to hold a button down to work, so test the tester on something you know is working before performing this test, like a lamp cord.

Safety When Turning ON Circuit Breakers
And speaking of safety, let us not forget a great tip about turning on and off breakers in an electrical panel. Always stand to the side of the panel and turn your head when you turn on the circuit breaker in the event that something blows up or flashes sparks.

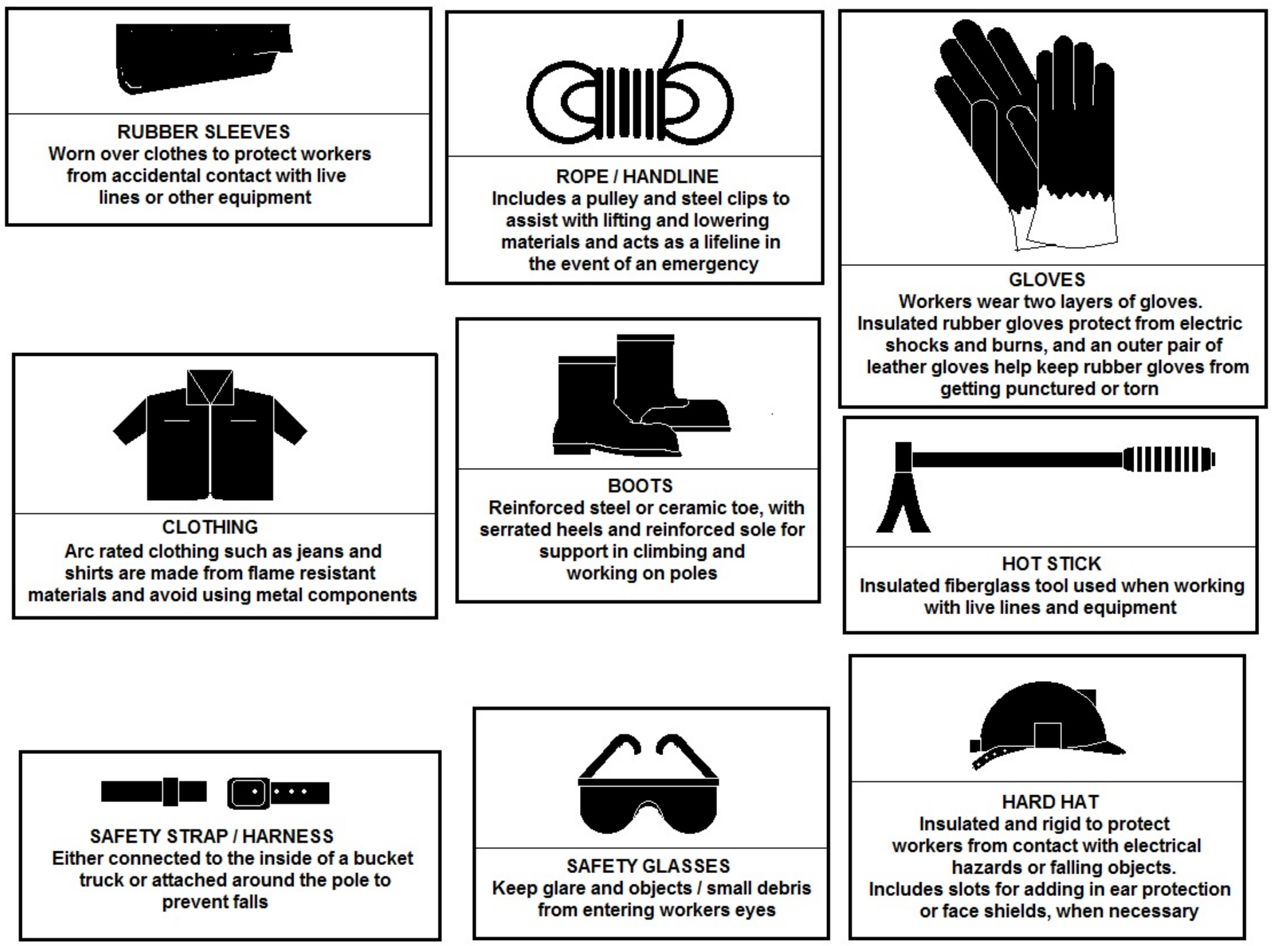
Protect Your Hands around Electricity
Hand protection is the next safety method. Gloves can protect the hands from sharp edges of cables, boxes, panels, and tools. Gloves also protect your hands from cold weather, water, and extreme conditions. Rubber gloves and high voltage gloves can protect you from electrical shock.

Safety Glasses for Electrical Safety

Safety glasses protect your eyes from dust and debris when sawing and drilling. This is especially true when working overhead. They can also protect your eyes from fragments and things when cutting wires.

Appropriate Safety Gear

To avoid serious injury due to working with electricity, electrical devices, tools, boxes, wire, panels and equipment, always wear the appropriate safety gear. These include safety glasses, rubber-soled shoes, gloves, and dust masks. Here are seven quick safety tips to consider when you are tackling an electrical project.



ELECTRICAL PERSONAL PROTECTIVE EQUIPMENT

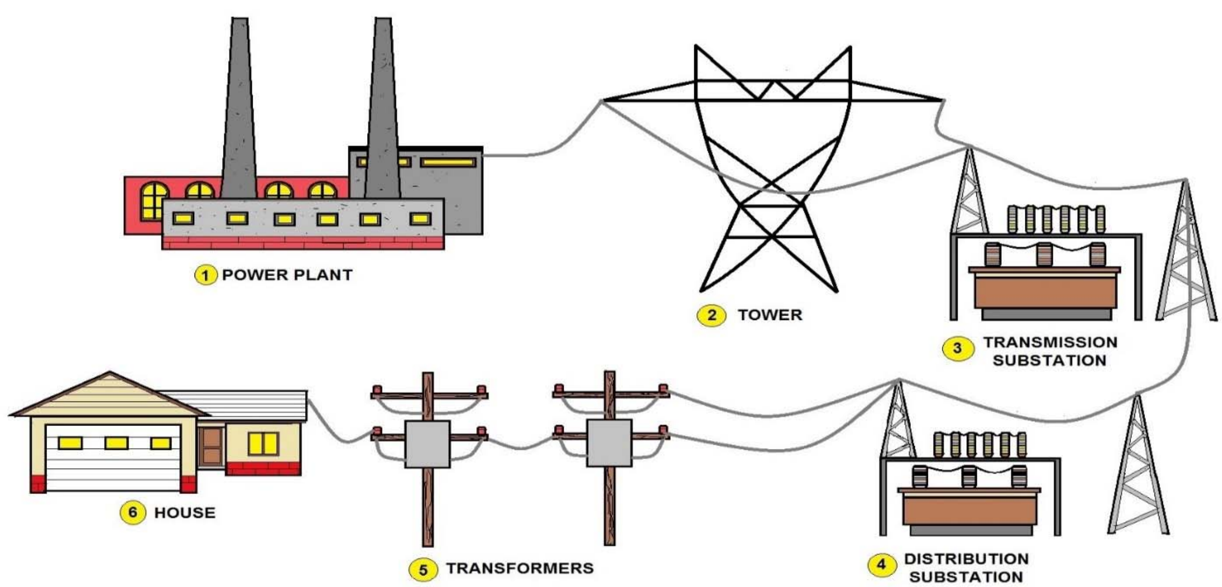
Electricity Distribution Sub-Section Introduction

Electricity distribution is the final stage in the delivery of electricity to end users. A distribution system's network carries electricity from the transmission system and delivers it to consumers. Typically, the network would include medium-voltage (2kV to 34.5kV) power lines, substations and pole-mounted transformers, low-voltage (less than 1 kV) distribution wiring and sometimes meters.

The modern distribution system begins as the primary circuit leaves the sub-station and ends as the secondary service enters the customer's meter socket by way of a service drop. Distribution circuits serve many customers. The voltage used is appropriate for the shorter distance and varies from 2,300 to about 35,000 volts depending on utility standard practice, distance, and load to be served. Distribution circuits are fed from a transformer located in an electrical substation, where the voltage is reduced from the high values used for power transmission.

Conductors for distribution may be carried on overhead pole lines, or in densely populated areas, buried underground. Urban and suburban distribution is done with three-phase systems to serve both residential, commercial, and industrial loads. Distribution in rural areas may be only single-phase if it is not economical to install three-phase power for relatively few and small customers.

Only large consumers are fed directly from distribution voltages; most utility customers are connected to a transformer, which reduces the distribution voltage to the relatively low voltage used by lighting and interior wiring systems. The transformer may be pole-mounted or set on the ground in a protective enclosure. In rural areas a pole-mount transformer may serve only one customer, but in more built-up areas multiple customers may be connected. In very dense city areas, a secondary network may be formed with many transformers feeding into a common bus at the utilization voltage. Each customer has a service drop connection and a meter for billing. (Some very small loads, such as yard lights, may be too small to meter and so are charged only a monthly rate.)



POWER-TO-HOME PROGRESSION

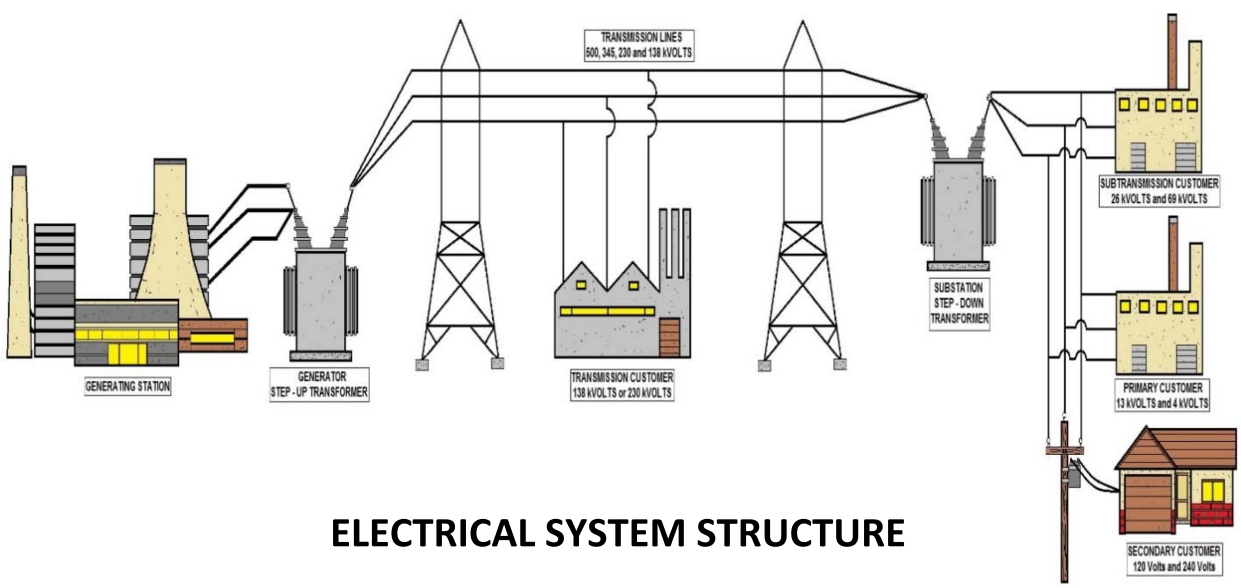
A ground connection to local earth is normally provided for the customer's system as well as for the equipment owned by the utility. The purpose of connecting the customer's system to ground is to limit the voltage that may develop if high voltage conductors fall down onto lower-voltage conductors which are usually mounted lower to the ground, or if a failure occurs within a distribution transformer. If all conductive objects are bonded to the same earth grounding system, the risk of electric shock is minimized.

However, multiple connections between the utility ground and customer ground can lead to stray voltage problems; customer piping, swimming pools or other equipment may develop objectionable voltages.
These problems may be difficult to resolve since they often originate from places other than the customer's premises.

Distribution networks are typically of two types, radial or interconnected. A radial network leaves the station and passes through the network area with no normal connection to any other supply. This is typical of long rural lines with isolated load areas. An interconnected network is generally found in more urban areas and will have multiple connections to other points of supply. These points of connection are normally open but allow various configurations by the operating utility by closing and opening switches.

Operation of these switches may be by remote control from a control center or by a lineman. The benefit of the interconnected model is that in the event of a fault or required maintenance a small area of network can be isolated and the remainder kept on supply.

Within these networks there may be a mix of overhead line construction utilizing traditional utility poles and wires and, increasingly, underground construction with cables and indoor or cabinet substations. However, underground distribution is significantly more expensive than overhead construction. In part to reduce this cost, underground power lines are sometimes co-located with other utility lines in what are called common utility ducts. Distribution feeders emanating from a substation are generally controlled by a circuit breaker which will open when a fault is detected. Automatic circuit reclosers may be installed to further segregate the feeder thus minimizing the impact of faults.



ELECTRICAL SYSTEM STRUCTURE

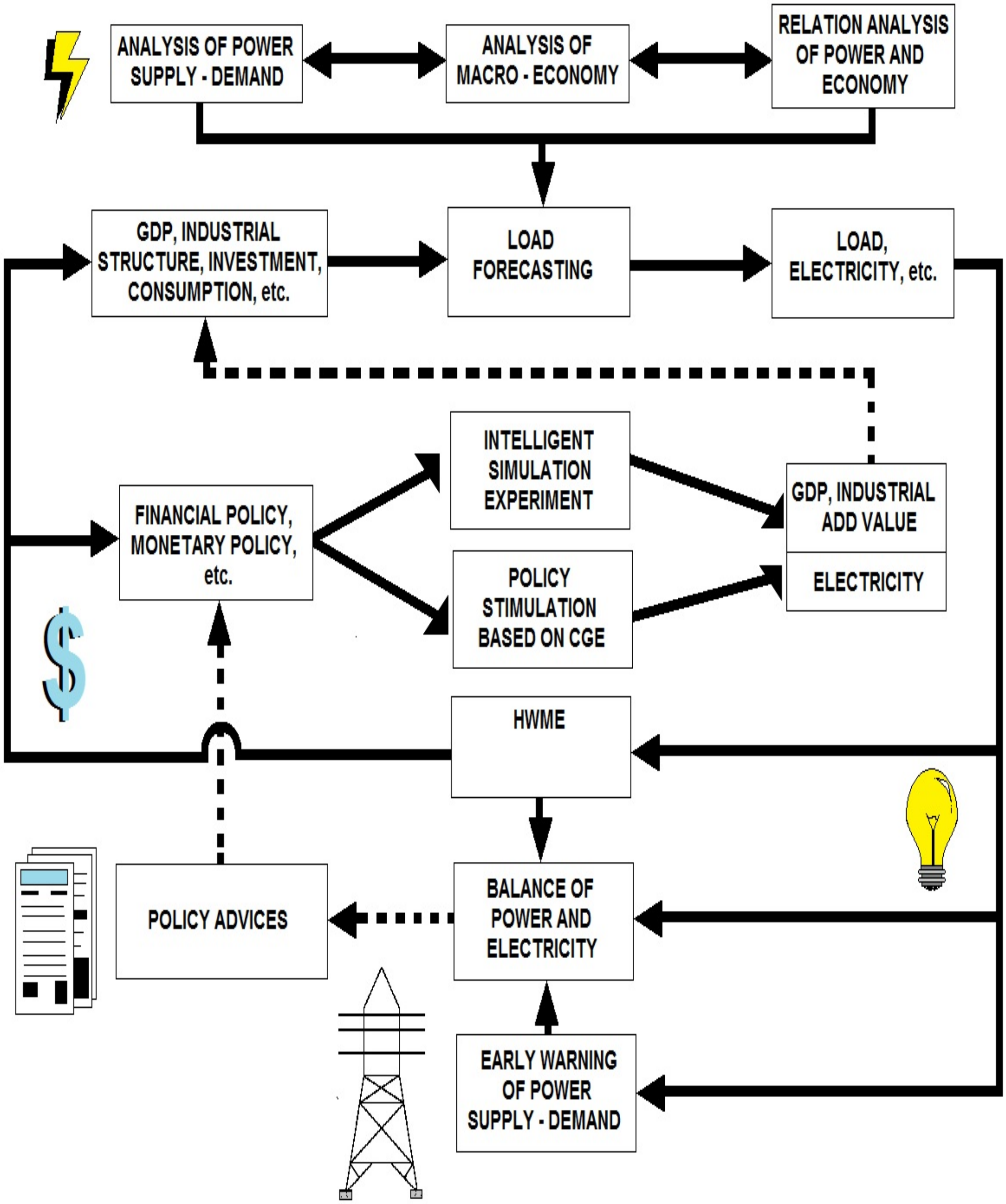
Long feeders experience voltage drop requiring capacitors or voltage regulators to be installed.

Characteristics of the supply given to customers are generally mandated by contract between the supplier and customer. Variables of the supply include:

- AC or DC - Virtually all public electricity supplies are AC today. Users of large amounts of DC power such as some electric railways, telephone exchanges and industrial processes such as aluminum smelting usually either operate their own or have adjacent dedicated generating equipment, or use rectifiers to derive DC from the public AC supply
- Nominal voltage, and tolerance (for example, +/- 5 per cent)
- Frequency, commonly 50 or 60 Hz, 16.7 Hz and 25 Hz for some railways and, in a few older industrial and mining locations, 25 Hz.
- Phase configuration (single-phase, polyphase including two-phase and three-phase)
- Maximum demand (some energy providers measure as the largest mean power delivered within a 15 or 30-minute period during a billing period)
- Load factor, expressed as a ratio of average load to peak load over a period of time. Load factor indicates the degree of effective utilization of equipment (and capital investment) of distribution line or system.
- Power factor of connected load
- Earthing systems - TT, TN-S, TN-C-S or TN-C
- Prospective short circuit current
- Maximum level and frequency of occurrence of transients

Reconfiguration, by exchanging the functional links between the elements of the system, represents one of the most important measures which can improve the operational performance of a distribution system.

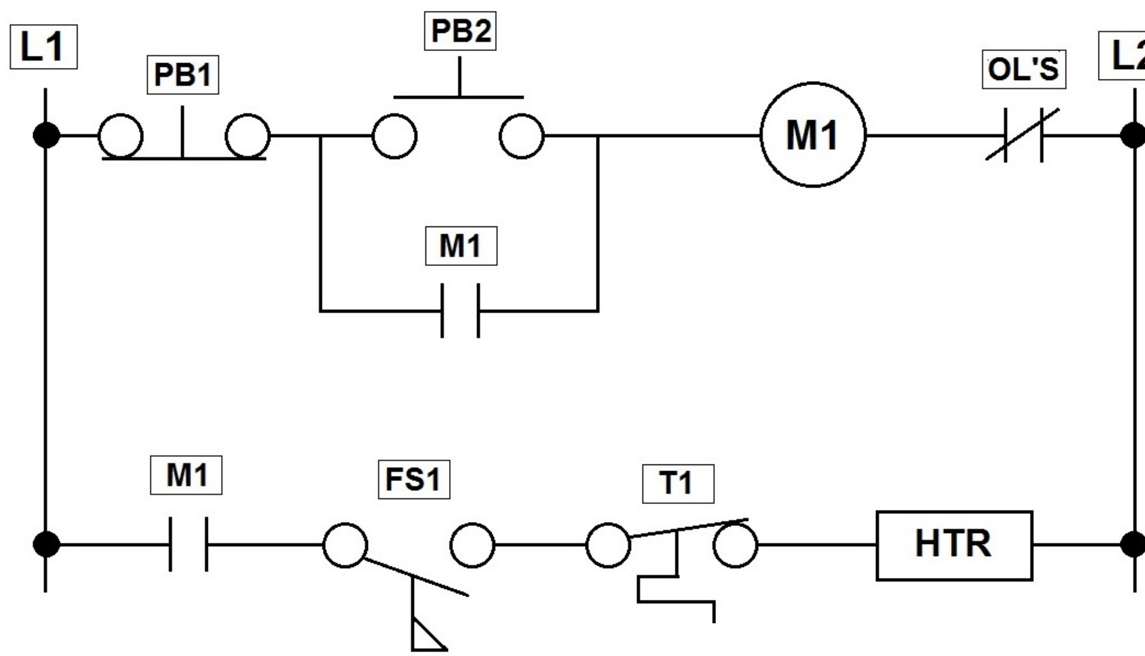
The problem of optimization through the reconfiguration of a power distribution system, in terms of its definition, is a historical single objective problem with constraints. Since 1975, when Merlin and Back introduced the idea of distribution system reconfiguration for active power loss reduction, until nowadays, a lot of researchers have proposed diverse methods and algorithms to solve the reconfiguration problem as a single objective problem.



PRICIPLES OF ELECTRICITY FLOW DIAGRAM

Electronics Introduction

Electronics deals with electrical circuits that involve active electrical components such as vacuum tubes, transistors, diodes and integrated circuits, and associated passive interconnection technologies. The nonlinear behavior of active components and their ability to control electron flows makes amplification of weak signals possible and electronics is widely used in information processing, telecommunications, and signal processing. The ability of electronic devices to act as switches makes digital information processing possible. Interconnection technologies such as circuit boards, electronics packaging technology, and other varied forms of communication infrastructure complete circuit functionality and transform the mixed components into a regular working system.



Electronics is distinct from electrical and electro-mechanical science and technology, which deals with the generation, distribution, switching, storage, and conversion of electrical energy to and from other energy forms using wires, motors, generators, batteries, switches, relays, transformers, resistors, and other passive components.

This distinction started around 1906 with the invention by Lee De Forest of the triode, which made electrical amplification of weak radio signals and audio signals possible with a non-mechanical device. Until 1950 this field was called "radio technology" because its principal application was the design and theory of radio transmitters, receivers, and vacuum tubes.

Today, most electronic devices use semiconductor components to perform electron control. The study of semiconductor devices and related technology is considered a branch of solid state physics, whereas the design and construction of electronic circuits to solve practical problems come under electronics engineering.

Radio
Faraday's and Ampère's work showed that a time-varying magnetic field acted as a source of an electric field, and a time-varying electric field was a source of a magnetic field. Thus, when either field is changing in time, then a field of the other is necessarily induced. Such a phenomenon has the properties of a wave, and is naturally referred to as an electromagnetic wave. Electromagnetic waves were analyzed theoretically by James Clerk Maxwell in 1864.

Maxwell developed a set of equations that could unambiguously describe the interrelationship between electric field, magnetic field, electric charge, and electric current. He could moreover prove that such a wave would necessarily travel at the speed of light, and thus light itself was a form of electromagnetic radiation. Maxwell's Laws, which unify light, fields, and charge are one of the great milestones of theoretical physics.

Thus, the work of many researchers enabled the use of electronics to convert signals into high frequency oscillating currents, and via suitably shaped conductors, electricity permits the transmission and reception of these signals via radio waves over very long distances.

Factors in Lethality of Electric Shock

The lethality of an electric shock is dependent on several variables:

- Current. The higher the current, the more likely it is lethal. Since current is proportional to voltage when resistance is fixed (ohm's law), high voltage is an indirect risk for producing higher currents.
- Duration. The longer the duration, the more likely it is lethal—safety switches may limit time of current flow
- Pathway. If current flows through the heart muscle, it is more likely to be lethal.
- High voltage (over about 600 volts). In addition to greater current flow, high voltage may cause dielectric breakdown at the skin, thus lowering skin resistance and allowing further increased current flow.

Other issues affecting lethality are frequency, which is an issue in causing cardiac arrest or muscular spasms. Very high frequency electric current causes tissue burning, but does not penetrate the body far enough to cause cardiac arrest. Also important is the pathway: if the current passes through the chest or head, there is an increased chance of death. From a main circuit or power distribution panel the damage is more likely to be internal, leading to cardiac arrest. Another factor is that cardiac tissue has a chronaxie (response time) of about 3 milliseconds, so electricity at frequencies of higher than about 333 Hz requires more current to cause fibrillation than is required at lower frequencies.

The comparison between the dangers of alternating current at typical power transmission frequencies (i.e., 50 or 60 Hz), and direct current has been a subject of debate ever since the War of Currents in the 1880s. Animal experiments conducted during this time suggested that alternating current was about twice as dangerous as direct current per unit of current flow (or per unit of applied voltage).

It is sometimes suggested that human lethality is most common with alternating current at 100–250 volts; however, death has occurred below this range, with supplies as low as 32 volts. Assuming a steady current flow (as opposed to a shock from a capacitor or from static electricity), shocks above 2,700 volts are often fatal, with those above 11,000 volts being usually fatal.

Electrical Principles and Application Sub-Section

An electric circuit is formed when a conductive path is created to allow free electrons to continuously move. This continuous movement of free electrons through the conductors of a circuit is called a *current*, and it is often referred to in terms of "flow," just like the flow of a liquid through a hollow pipe.

The force motivating electrons to "flow" in a circuit is called *voltage*. Voltage is a specific measure of potential energy that is always relative between two points. When we speak of a certain amount of voltage being present in a circuit, we are referring to the measurement of how much *potential* energy exists to move electrons from one particular point in that circuit to another particular point. Without reference to *two* particular points, the term "voltage" has no meaning.

Free electrons tend to move through conductors with some degree of friction, or opposition to motion. This opposition to motion is more properly called *resistance*. The amount of current in a circuit depends on the amount of voltage available to motivate the electrons, and also the amount of resistance in the circuit to oppose electron flow. Just like voltage, resistance is a quantity relative between two points. For this reason, the quantities of voltage and resistance are often stated as being "between" or "across" two points in a circuit.

To be able to make meaningful statements about these quantities in circuits, we need to be able to describe their quantities in the same way that we might quantify mass, temperature, volume, length, or any other kind of physical quantity. For mass we might use the units of "kilogram" or "gram." For temperature we might use degrees Fahrenheit or degrees Celsius. Here are the standard units of measurement for electrical current, voltage, and resistance:

Quantity	Symbol	Unit of Measurement	Unit Abbreviation
Current	I	Ampere ("Amp")	A
Voltage	E *or* V	Volt	V
Resistance	R	Ohm	Ω

The "symbol" given for each quantity is the standard alphabetical letter used to represent that quantity in an algebraic equation. Standardized letters like these are common in the disciplines of physics and engineering, and are internationally recognized. The "unit abbreviation" for each quantity represents the alphabetical symbol used as a shorthand notation for its particular unit of measurement. And, yes, that strange-looking "horseshoe" symbol is the capital Greek letter Ω.

Each unit of measurement is named after a famous experimenter in electricity: The *amp* after the Frenchman Andre M. Ampere, the *volt* after the Italian Alessandro Volta, and the *ohm* after the German Georg Simon Ohm.

The mathematical symbol for each quantity is meaningful as well. The "R" for resistance and the "V" for voltage are both self-explanatory, whereas "I" for current seems a bit weird.

The "I" is thought to have been meant to represent "Intensity" (of electron flow), and the other symbol for voltage, "E," stands for "Electromotive force." From what research I've been able to do, there seems to be some dispute over the meaning of "I." The symbols "E" and "V" are interchangeable for the most part, although some texts reserve "E" to represent voltage across a source (such as a battery or generator) and "V" to represent voltage across anything else.

All of these symbols are expressed using capital letters, except in cases where a quantity (especially voltage or current) is described in terms of a brief period of time (called an "instantaneous" value). For example, the voltage of a battery, which is stable over a long period of time, will be symbolized with a capital letter "E," while the voltage peak of a lightning strike at the very instant it hits a power line would most likely be symbolized with a lower-case letter "e" (or lower-case "v") to designate that value as being at a single moment in time. This same lower-case convention holds true for current as well, the lower-case letter "i" representing current at some instant in time.

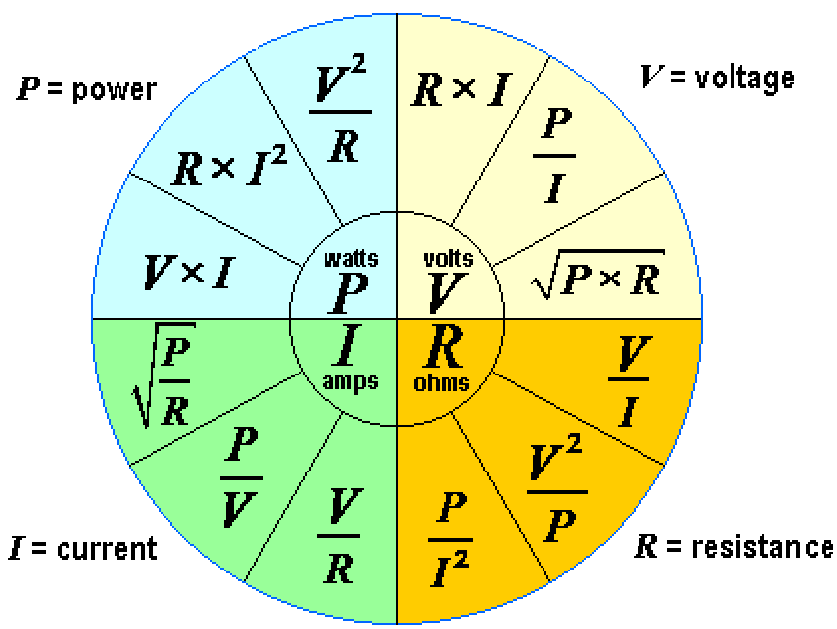
Most direct-current (DC) measurements, however, being stable over time, will be symbolized with capital letters.

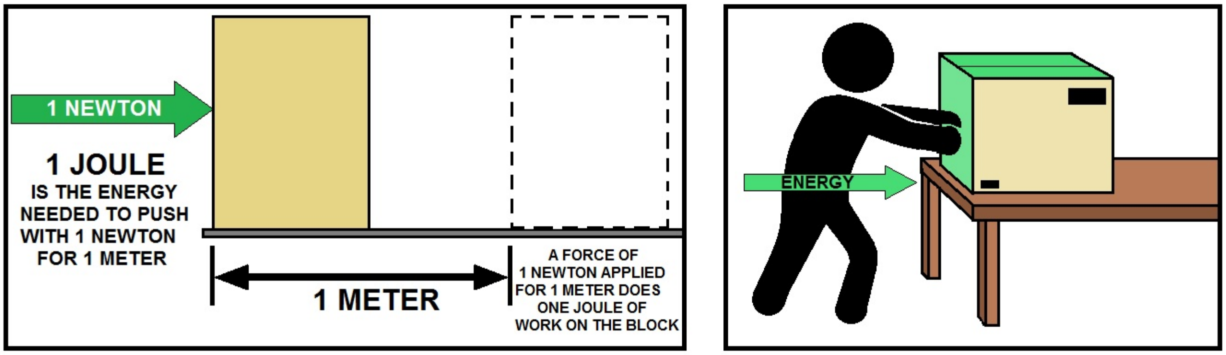
One foundational unit of electrical measurement, often taught in the beginnings of electronics courses but used infrequently afterwards, is the unit of the *coulomb*, which is a measure of electric charge proportional to the number of electrons in an imbalanced state.

One coulomb of charge is equal to 6,250,000,000,000,000,000 electrons. The symbol for electric charge quantity is the capital letter "Q," with the unit of coulombs abbreviated by the capital letter "C."

It so happens that the unit for electron flow, the amp, is equal to 1 coulomb of electrons passing by a given point in a circuit in 1 second of time.

Cast in these terms, current is the *rate of electric charge motion* through a conductor.





JOULE ENERGY ILLUSTRATION

As stated before, voltage is the measure of *potential energy per unit charge* available to motivate electrons from one point to another. Before we can precisely define what a "volt" is, we must understand how to measure this quantity we call "potential energy." The general metric unit for energy of any kind is the *joule*, equal to the amount of work performed by a force of 1 newton exerted through a motion of 1 meter (in the same direction).

In British units, this is slightly less than 3/4 pound of force exerted over a distance of 1 foot. Put in common terms, it takes about 1 joule of energy to lift a 3/4 pound weight 1 foot off the ground, or to drag something a distance of 1 foot using a parallel pulling force of 3/4 pound.

Defined in these scientific terms, 1 volt is equal to 1 joule of electric potential energy per (divided by) 1 coulomb of charge. Thus, a 9-volt battery releases 9 joules of energy for every coulomb of electrons moved through a circuit.

Common Electrical Units used in Formulas and Equations are:

- **Volt** - unit of electrical potential or motive force - potential is required to send one ampere of current through one ohm of resistance
- **Ohm** - unit of resistance - one ohm is the resistance offered to the passage of one ampere when impelled by one volt
- **Ampere** - units of current - one ampere is the current which one volt can send through a resistance of one ohm
- **Watt** - unit of electrical energy or power - one watt is the product of one ampere and one volt - one ampere of current flowing under the force of one volt gives one watt of energy
- **Volt Ampere** - product of volts and amperes as shown by a voltmeter and ammeter - in direct current systems the volt ampere is the same as watts or the energy delivered - in alternating current systems - the volts and amperes may or may not be 100% synchronous - when synchronous the volt amperes equals the watts on a wattmeter - when not synchronous volt amperes exceed watts - reactive power
- **Kilovolt Ampere** - one kilovolt ampere - KVA - is equal to 1,000 volt amperes
- **Power Factor** - ratio of watts to volt amperes

Electric Power Formulas

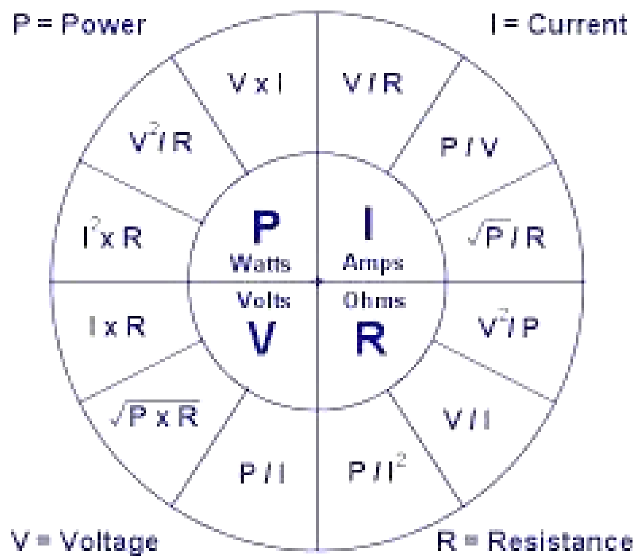
$P = V\,I$ (1a)

$P = R\,I^2$ (1b)

$P = V^2/ R$ (1c)

where

P = power (watts, W)
V = voltage (volts, V)
I = current (amperes, A)
R = resistance (ohms, Ω)



Electric Current Formulas

$I = V / R$ (2a)

$I = P / V$ (2b)

$I = (P / R)^{1/2}$ (2c)

Electric Resistance Formulas

$R = V / I$ (3a)

$R = V^2/ P$ (3b)

$R = P / I^2$ (3c)

Electrical Potential Formulas - Ohms Law

Ohms law can be expressed as:

$V = R\,I$ (4a)

$V = P / I$ (4b)

$V = (P\,R)^{1/2}$ (4c)

Example - Ohm's law

A *12 volt* battery supplies power to a resistance of *18 ohms*.

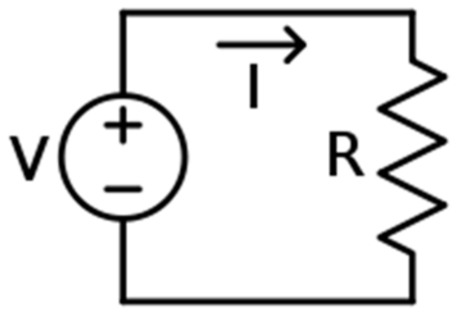
$I = (12\ V) / (18\ \Omega)$

$= 0.67\ (A)$

Electronic Circuit Introduction

A Basic Electric Circuit

The voltage source V on the left drives a current I around the circuit, delivering electrical energy into the resistor R. From the resistor, the current returns to the source, completing the circuit.



An electric circuit is an interconnection of electric components such that electric charge is made to flow along a closed path (a circuit), usually to perform some useful task.

The components in an electric circuit can take many forms, which can include elements such as resistors, capacitors, switches, transformers and electronics. Electronic circuits contain active components, usually semiconductors, and typically exhibit non-linear behavior, requiring complex analysis.

The simplest electric components are those that are termed passive and linear: while they may temporarily store energy, they contain no sources of it, and exhibit linear responses to stimuli.

The resistor is perhaps the simplest of passive circuit elements: as its name suggests, it resists the current through it, dissipating its energy as heat. The resistance is a consequence of the motion of charge through a conductor: in metals, for example, resistance is primarily due to collisions between electrons and ions.

Ohm's law is a basic law of circuit theory, stating that the current passing through a resistance is directly proportional to the potential difference across it. The resistance of most materials is relatively constant over a range of temperatures and currents; materials under these conditions are known as 'ohmic'.

The ohm, the unit of resistance, was named in honor of Georg Ohm, and is symbolized by the Greek letter Ω. 1 Ω is the resistance that will produce a potential difference of one volt in response to a current of one amp

The capacitor is a development of the Leyden jar and is a device that can store charge, and thereby storing electrical energy in the resulting field. It consists of two conducting plates separated by a thin insulating dielectric layer; in practice, thin metal foils are coiled together, increasing the surface area per unit volume and therefore the capacitance.

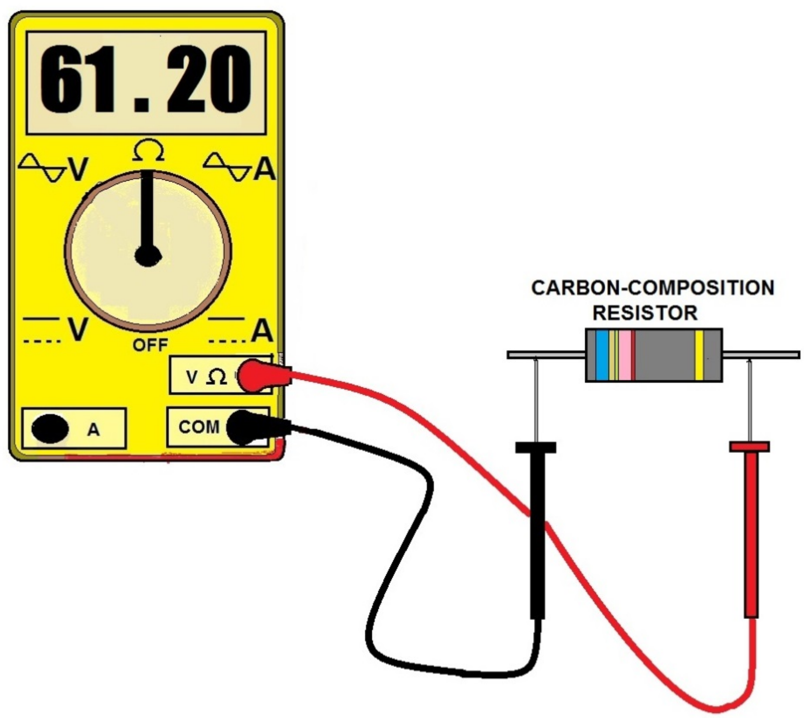
The unit of capacitance is the farad, named after Michael Faraday, and given the symbol F: one farad is the capacitance that develops a potential difference of one volt when it stores a charge of one coulomb.

A capacitor connected to a voltage supply initially causes a current as it accumulates charge; this current will however decay in time as the capacitor fills, eventually falling to zero. A capacitor will therefore not permit a steady state current, but instead blocks it.

The inductor is a conductor, usually a coil of wire, which stores energy in a magnetic field in response to the current through it. When the current changes, the magnetic field does too, inducing a voltage between the ends of the conductor. The induced voltage is proportional to the time rate of change of the current.

The constant of proportionality is termed the inductance. The unit of inductance is the henry, named after Joseph Henry, a contemporary of Faraday.

One henry is the inductance that will induce a potential difference of one volt if the current through it changes at a rate of one ampere per second. The inductor's behavior is in some regards converse to that of the capacitor: it will freely allow an unchanging current, but opposes a rapidly changing one.



TESTING A RESISTOR

Alternating Current Introduction

In alternating current (AC, also ac), the movement of electric charge periodically reverses direction. In direct current (DC, also dc), the flow of electric charge is only in one direction.

AC is the form in which electric power is delivered to businesses and residences. The usual waveform of an AC power circuit is a sine wave. In certain applications, different waveforms are used, such as triangular or square waves. Audio and radio signals carried on electrical wires are also examples of alternating current. In these applications, an important goal is often the recovery of information encoded (or modulated) onto the AC signal.

Occurrences
Natural observable examples of electrical current include lightning, static electricity, and the solar wind, the source of the polar auroras.

Man-made occurrences of electric current include the flow of conduction electrons in metal wires such as the overhead power lines that deliver electrical energy across long distances and the smaller wires within electrical and electronic equipment. Eddy currents are electric currents that occur in conductors exposed to changing magnetic fields. Similarly, electric currents occur, particularly in the surface, of conductors exposed to electromagnetic waves. When oscillating electric currents flow at the correct voltages within radio antennas, radio waves are generated.

In electronics, other forms of electric current include the flow of electrons through resistors or through the vacuum in a vacuum tube, the flow of ions inside a battery or a neuron, and the flow of holes within a semiconductor.

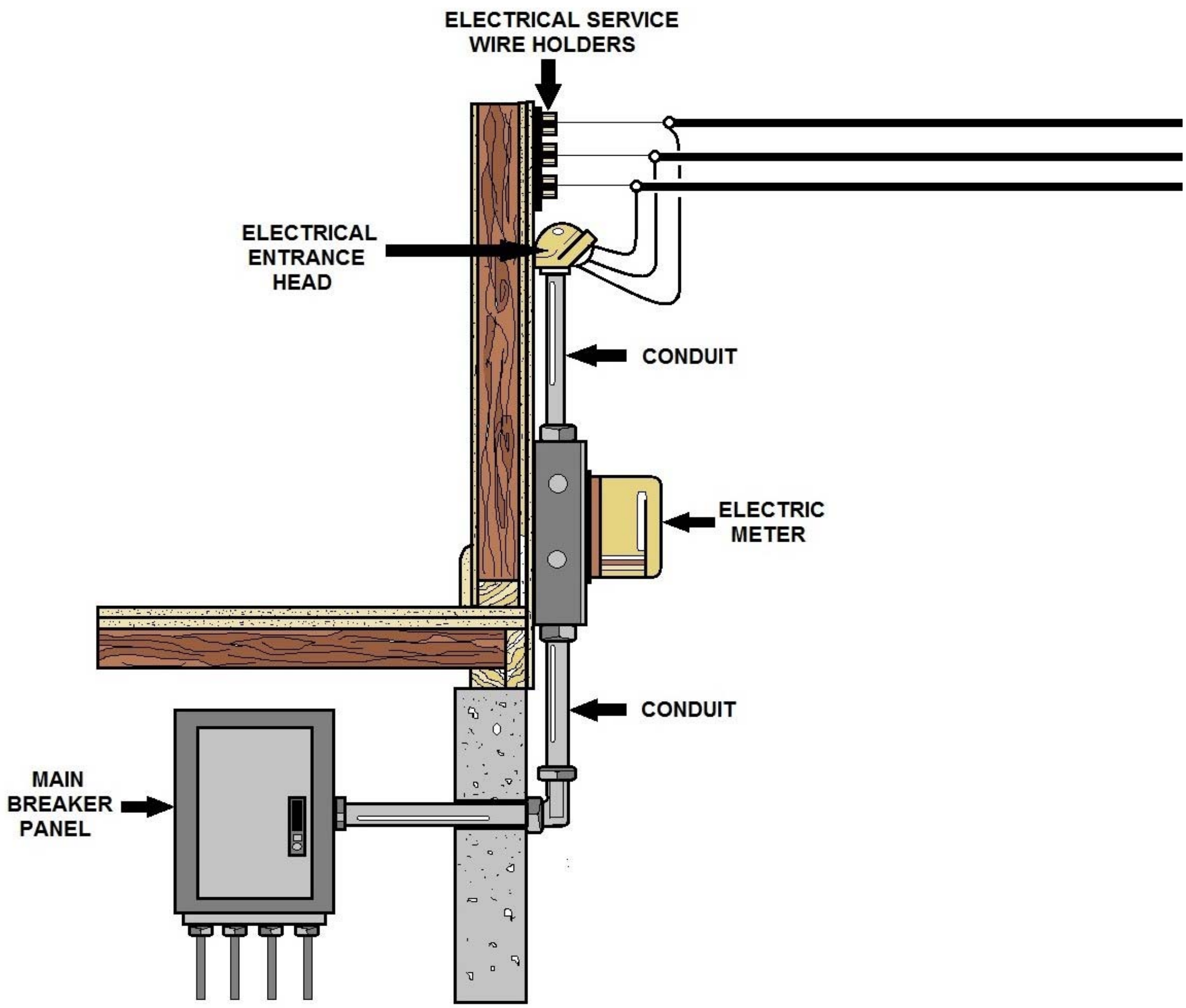
Current Measurement
At the circuit level, there are various techniques that can be used to measure current:

- Shunt resistors
- Hall effect current sensor transducers
- Transformers (however DC cannot be measured)
- Magnetoresistive field sensors

Resistive Heating
Joule heating, also known as *ohmic heating* and *resistive heating*, is the process by which the passage of an electric current through a conductor releases heat. It was first studied by James Prescott Joule in 1841. Joule immersed a length of wire in a fixed mass of water and measured the temperature rise due to a known current through the wire for a 30-minute period. By varying the current and the length of the wire he deduced that the heat produced was proportional to the square of the current multiplied by the electrical resistance of the wire.

$$Q \propto I^2 R$$

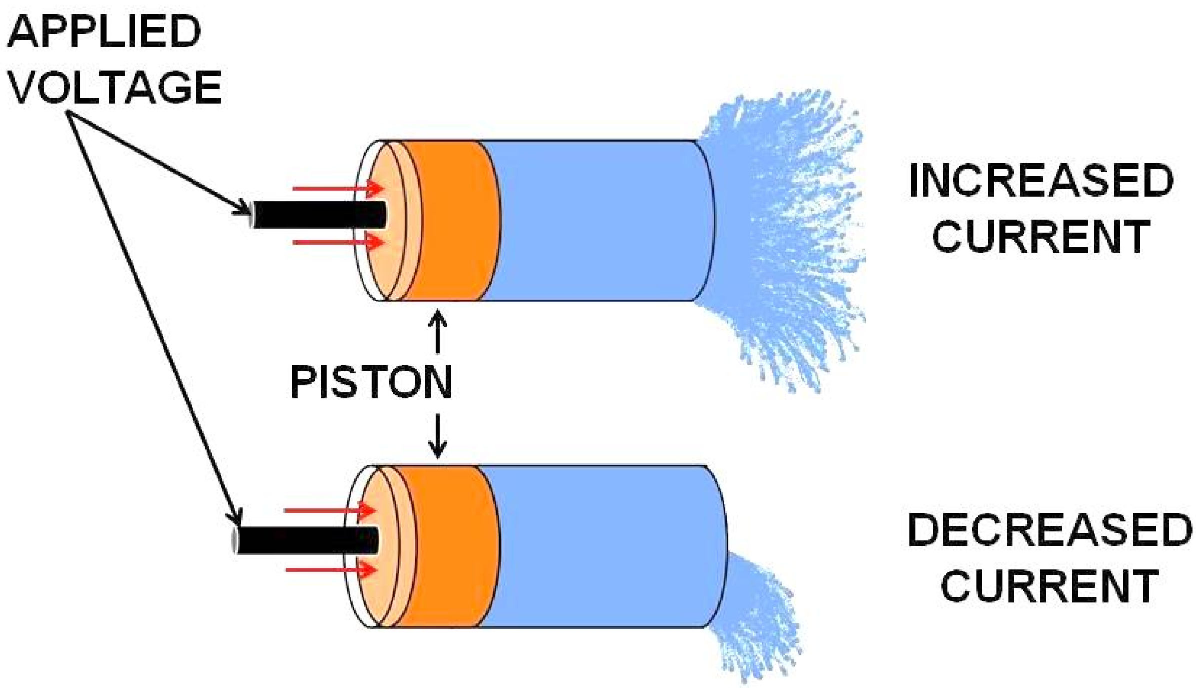
This relationship is known as Joule's First Law. The SI unit of energy was subsequently named the joule and given the symbol *J*. The commonly known unit of power, the watt, is equivalent to one joule per second.



BASIC HOME ELECTRICITY

Volt – Introduction

The **volt** (symbol: **V**) is the SI derived unit for electric potential (voltage), electric potential difference, and electromotive force. The volt is named in honor of the Italian physicist Alessandro Volta (1745–1827), who invented the voltaic pile, possibly the first chemical battery.



VOLTAGE AND CURRENT

Definition
A single volt is defined as the difference in electric potential between two points of a conducting wire when an electric current of one ampere dissipates one watt of power between those points. It is also equal to the potential difference between two parallel, infinite planes spaced 1 meter apart that create an electric field of 1 newton per coulomb. Additionally, it is the potential difference between two points that will impart one joule of energy per coulomb of charge that passes through it. It can be expressed in terms of SI base units (m, kg, s, and A) as:

$$V = \frac{kg \cdot m^2}{A \cdot s^3}.$$

It can also be expressed as amps × ohms (Ohm's law), power per unit current (Joule's law), or energy per unit charge:

$$V = A \cdot \Omega = \frac{W}{A} = \frac{J}{C}.$$

Josephson Junction Definition
Between 1990 and 1997, the volt was calibrated using the Josephson effect for exact voltage-to-frequency conversion, combined with cesium-133 time reference, as decided by the 18th General Conference on Weights and Measures. The following value for the Josephson constant is used:

$K_{\{J\text{-}90\}} = 2e/h = 0.4835979$ GHz/μV,

where e is the elementary charge and h is the Planck constant.

This is typically used with an array of several thousand or tens of thousands of junctions, excited by microwave signals between 10 and 80 GHz (depending on the array design). Empirically, several experiments have shown that the method is independent of device design, material, measurement setup, etc., and no correction terms are required in a practical implementation.

History

ALESSANDRO VOLTA

In 1800, as the result of a professional disagreement over the galvanic response advocated by Luigi Galvani, Alessandro Volta developed the so-called Voltaic pile, a forerunner of the battery, which produced a steady electric current. Volta had determined that the most effective pair of dissimilar metals to produce electricity is zinc and silver. In the 1880s, the International Electrical Congress, now the International Electrotechnical Commission (IEC), approved the volt as the unit for electromotive force. They made the volt equal to 10^8 cgs units of voltage, the cgs system at the time being the customary system of units in science. They chose such a ratio because the cgs unit of voltage is inconveniently small and one volt in this definition is approximately the emf of a Daniell cell, the standard source of voltage in the telegraph systems of the day. At that time, the volt was defined as the potential difference [i.e., what is nowadays called the "voltage (difference)"] across a conductor when a current of one ampere dissipates one watt of power.

The international volt was defined in 1893 as 1/1.434 of the emf of a Clark cell. This definition was abandoned in 1908 in favor of a definition based on the international ohm and international ampere until the entire set of "reproducible units" was abandoned in 1948. Prior to the development of the Josephson junction voltage standard, the volt was maintained in national laboratories using specially constructed batteries called standard cells. The United States used a design called the Weston cell from 1905 to 1972.

Ampere- Introduction

The **Ampere** (SI unit symbol: A; SI dimension symbol: I), often shortened to **amp**, is the SI unit of electric current (quantity symbol: *I*, *i*) and is one of the seven SI base units. It is named after André-Marie Ampère (1775–1836), French mathematician and physicist, considered the father of electrodynamics.

In practical terms, the Ampere is a measure of the amount of electric charge passing a point in an electric circuit per unit time, with 6.241×10^{18} electrons (or one coulomb) per second constituting one ampere.

The practical definition may lead to confusion with the definition of the coulomb (i.e., 1 Ampere-second) and the ampere-hour (A·h), but in practical terms this means that measures of a constant current (e.g., the nominal flow of charge per second through a simple circuit) will be defined in amperes (e.g., "a 20 mA circuit") and the flow of charge through a circuit over a period of time will be defined in coulombs (e.g., "a variable-current circuit that flows a total of 10 coulombs over 5 seconds"). In this way, amperes can be viewed as a flow rate, i.e. number of (charged) particles transiting per unit time, and coulombs simply as the number of particles.

Definition

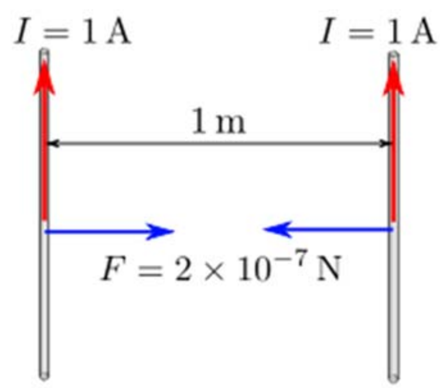


ILLUSTRATION OF THE DEFINITION OF THE AMPERE UNIT

Ampère's force law states that there is an attractive or repulsive force between two parallel wires carrying an electric current. This force is used in the formal definition of the ampere, which states that it is "the constant current that will produce an attractive force of 2×10^{-7} newton per meter of length between two straight, parallel conductors of infinite length and negligible circular cross section placed one meter apart in a vacuum".

The SI unit of charge, the coulomb, "is the quantity of electricity carried in 1 second by a current of 1 ampere". Conversely, a current of one Ampere is one coulomb of charge going past a given point per second:

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

In general, charge *Q* is determined by steady current *I* flowing for a time *t* as $Q = It$.

History

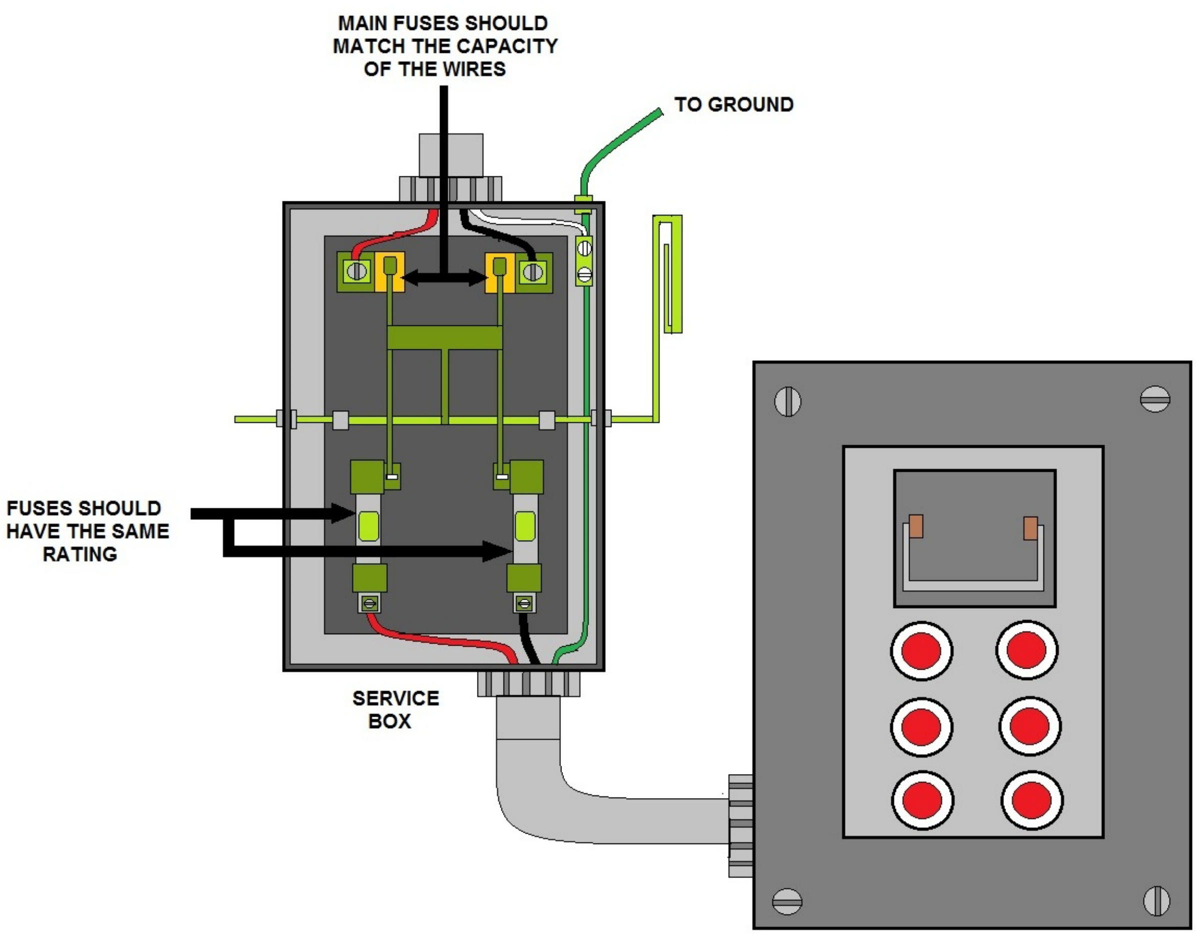
The ampere was originally defined as one tenth of the CGS system electromagnetic unit of current (now known as the abampere), the amount of current that generates a force of two dynes per centimeter of length between two wires one centimeter apart. The size of the unit was chosen so that the units derived from it in the MKSA system would be conveniently sized.

The "international ampere" was an early realization of the ampere, defined as the current that would deposit 0.001118 grams of silver per second from a silver nitrate solution. Later, more accurate measurements revealed that this current is 0.99985 A.

Realization

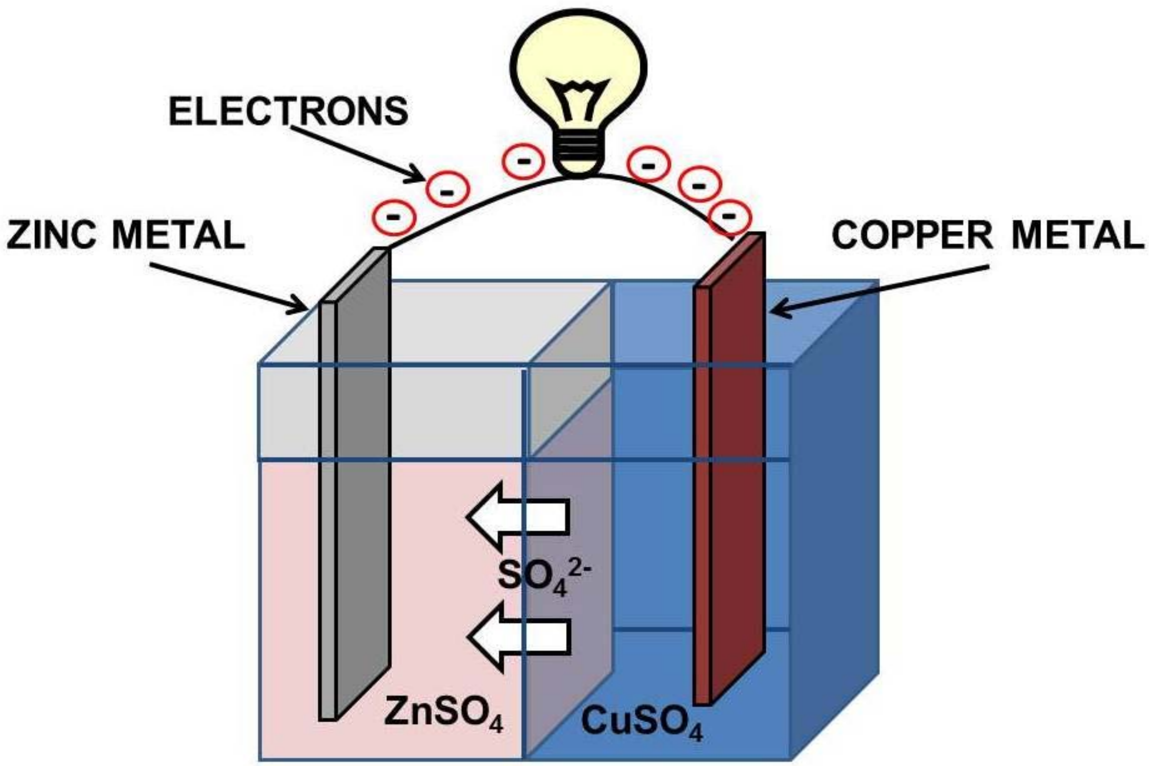
The standard ampere is most accurately realized using a watt balance, but is in practice maintained via Ohm's law from the units of electromotive force and resistance, the volt and the ohm, since the latter two can be tied to physical phenomena that are relatively easy to reproduce, the Josephson junction and the quantum Hall effect, respectively.

At present, techniques to establish the realization of an ampere have a relative uncertainty of approximately a few parts in 10^7, and involve realizations of the watt, the ohm and the volt.



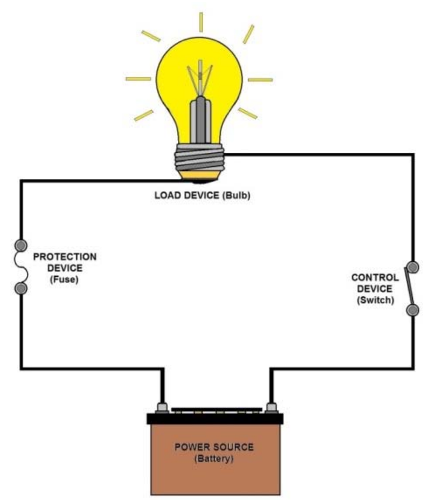
PROPERLY SIZING FUSES

Batteries Produce Electricity- Introduction



ELECTROCHEMICAL CELL

A battery produces electricity using two different metals in a chemical solution. A chemical reaction between the metals and the chemicals frees more electrons in one metal than in the other. One end of the battery is attached to one of the metals; the other end is attached to the other metal.



ELECTRICAL CIRCUIT

The end that frees more electrons develops a positive charge and the other end develops a negative charge. If a wire is attached from one end of the battery to the other, electrons flow through the wire to balance the electrical charge.

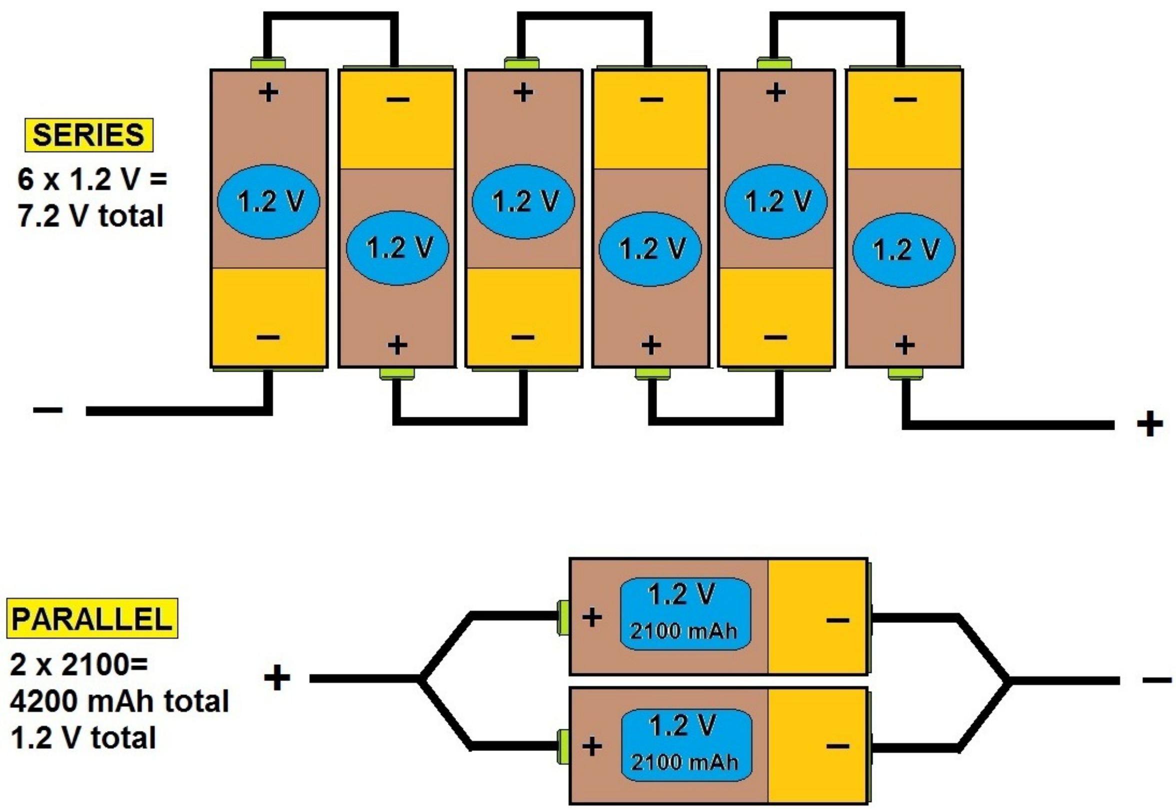
A load is a device that does work or performs a job. If a load — such as a light bulb — is placed along the wire, the electricity can do work as it flows through the wire.

Electrons flow from the negative end of the battery through the wire to the light bulb. The electricity flows through the wire in the light bulb and back to the positive end of the battery.

Electricity Travels in Circuits
Electricity travels in closed loops, or circuits. It must have a complete path before the electrons can move. If a circuit is open, the electrons cannot flow. When we flip on a light switch, we close a circuit. The electricity flows from an electric wire, through the light bulb, and back out another wire.

When we flip the switch off, we open the circuit. No electricity flows to the light. When we turn a light switch on, electricity flows through a tiny wire in the bulb. The wire gets very hot. It makes the gas in the bulb glow. When the bulb burns out, the tiny wire has broken. The path through the bulb is gone.

When we turn on the TV, electricity flows through wires inside the TV set, producing pictures and sound. Sometimes electricity runs motors — in washers or mixers. Electricity does a lot of work for us many times each day.



BATTER CELL CONNECTIONS

Testers and How They Work

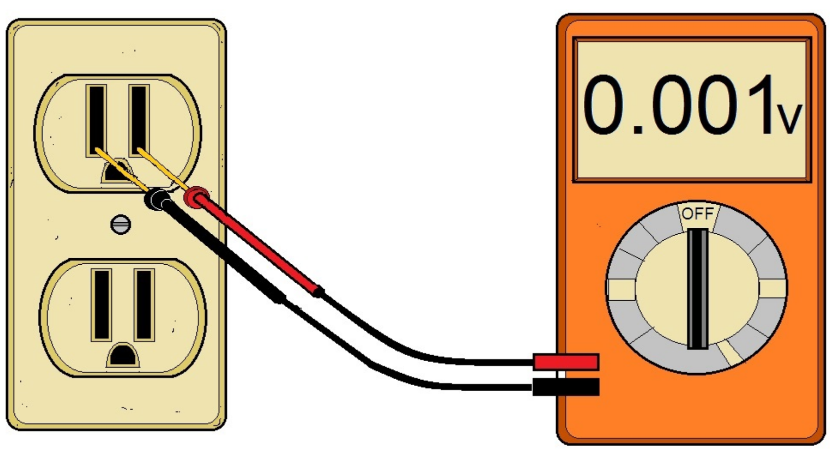
If the thought of working on an electrical circuit makes you cringe because the circuit may still be on or “hot”, then investing in a multi-meter, voltmeter or a neon-light tester should be your first order of business. These testers are relatively inexpensive and can protect you from electrical shock.

Neon testers, voltmeters and tick-tracers consist of a neon light bulb that is attached to two leads used for checking a circuit. When you press these two leads into an outlet, the bulb will light if the circuit is “hot” or on. If it doesn’t light, then the circuit is “dead” or off. Multi-meters come in analog or digital display. They test voltage, ohms and amperage while displaying the results on a screen or dial.

Always check to see if the tester is working properly by checking a circuit that you know is working properly before moving on. To double-check that an outlet is actually off, remove the outlet cover and test the screws on the sides of the outlet. You can also plug a lamp or vacuum into the outlet just to put your mind at ease.

Outlets and Testing
A typical outlet has three holes built into it. The shorter straight slot is the “hot” lead. The longer straight slot is the “neutral” lead. The slot that looks like a small circle hole is the ground.

To test the ground, test between the “hot” and “ground” slots. If the circuit is working and you have a good “ground” connection, the tester will light. The tester will also light if you test between the “hot” and “neutral” slots.Plug-in circuit testers are available that will test your circuit for you via three neon lights. They test for an open neutral, lack of a ground, wires on the wrong terminals, and no power.



USE OF A METER TO TEST AN OUTLET

Switches and Testing
To test a switch, remove the cover plate and check from one of the screws on the side of the switch to the bare copper wire (ground) or the metal box. Keep in mind that the box may not be grounded, especially if it’s a plastic box.

Testing Light Fixtures

When checking light fixture wiring, take down the light and using a “tick-tracer”, test the circuit to see if it working. This tester lights when you place it close to a wire that has current flowing through it.

To double-check the circuit, first turn off the power to that circuit. Now, remove the wire nuts from both the black “hot” wires and the white “neutral" wires. Separate these sets of wires so that they are not touching one another.

Turn the circuit back on and check between the black and white wires with the voltmeter or neon tester. Be careful not to touch the exposed wires. The voltmeter should show a reading of around 120 volts. Likewise, the neon tester should light if the circuit is working properly.

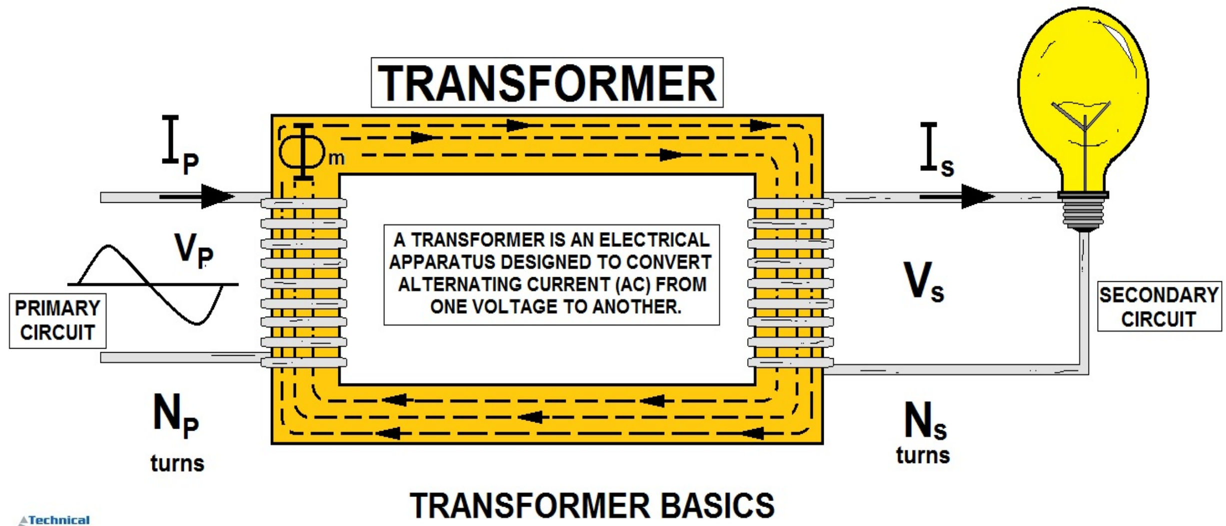
One of the easiest ways to check for faulty devices and parts, is to use a multi-tester, sometimes called a multi-meter. Testing continuity by using the ohm setting will tell you if the connection through the device is complete or if it has opened and is no longer usable.
For instance, if you place one of the test leads on one side of a fuse and the other lead on the other side of the fuse, you should show a short circuit or 0 ohms. If your meter shows infinite resistance, the fuse is bad and should be replaced.

To test something, turn the dial of the tester to the ohm setting. This portion of the dial has markings like X1, X10, XK1, etc... This simply means that on the X1 setting, the value of ohms shown on the dial is taken times 1 and that is the amount of ohms.

Let's say it shows 50 ohms. That means 50x1=50 ohms. With the dial set at X10, if the dial shows 50, 50x10=500 ohms. You can see the theory here. By adjusting the dial to another setting the multiples increase.

With the test leads apart and not touching, the meter needle should be all the way to the right, showing maximum ohms. On a digital meter, the screen will show infinite resistance.

By touching the two test leads together, either tester should show a 0 ohms reading. The digital will likely show a 0.00 reading. Sometimes meters have an audible continuity setting that looks like a diode. With this setting, when the test leads are touched together, the meter will show the reading and an audible alarm will sound. My tester has a constant beep sound.



Transformer Introduction- Helps to Move Electricity Efficiently Over Long Distances

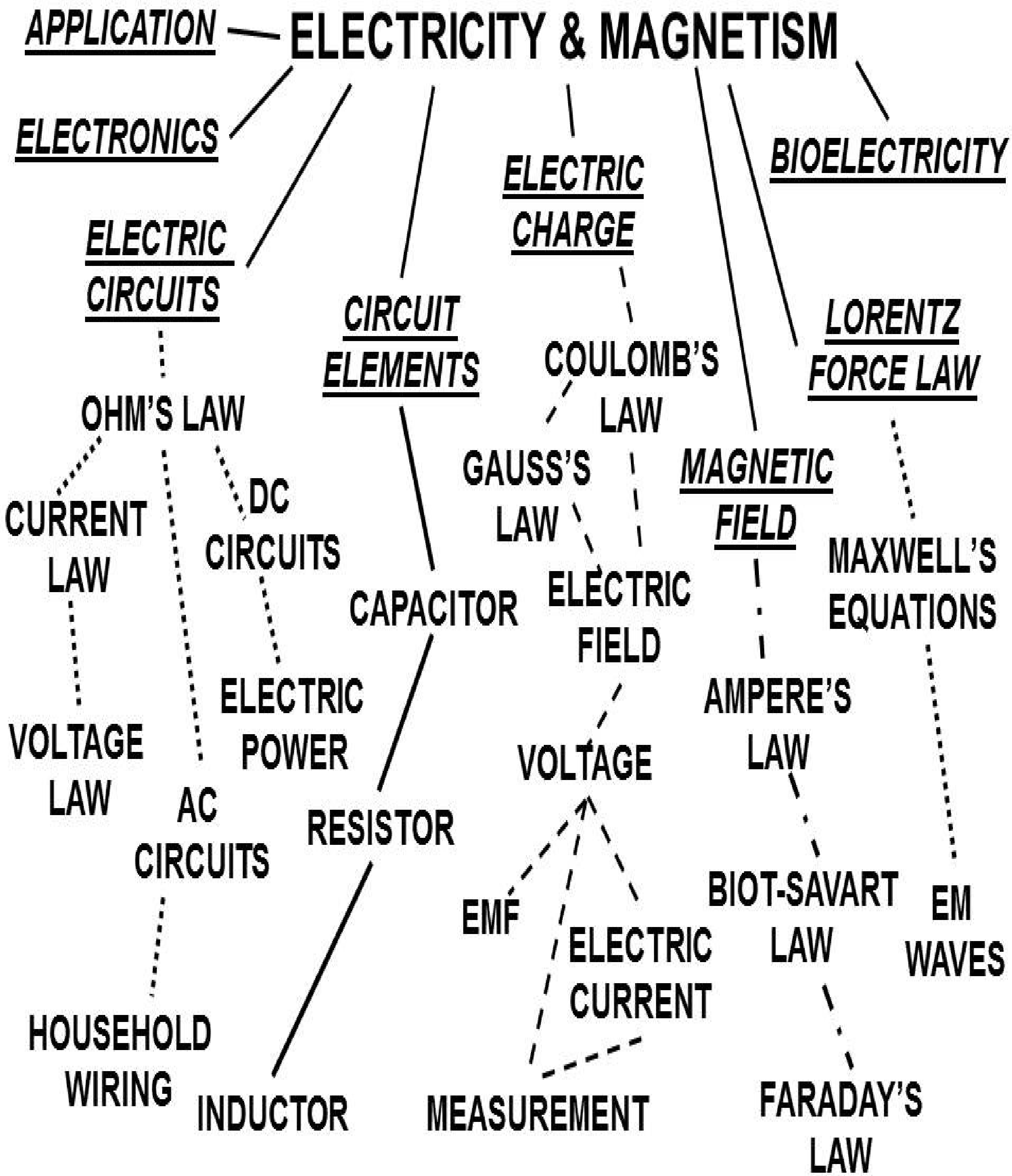
To solve the problem of sending electricity over long distances, William Stanley developed a device called a transformer. The transformer allowed electricity to be efficiently transmitted over long distances. This increased delivery range made it possible to supply electricity to homes and businesses located far from the electric generating plant.

The electricity produced by a generator travels along cables to a transformer, which changes electricity from low voltage to high voltage. Electricity can be moved long distances more efficiently using high voltage. Transmission lines are used to carry the electricity to a substation. Substations have transformers that change the high voltage electricity into lower voltage electricity. From the substation, distribution lines carry the electricity to homes, offices, and factories, which require low voltage electricity.

Electricity Is Measured in Watts and Kilowatts
Electricity is measured in units of power called watts. It was named to honor James Watt, the inventor of the steam engine. One watt is a very small amount of power. It would require nearly 750 watts to equal one horsepower. A kilowatt is the same as 1,000 watts.

Electricity Use Over Time Is Measured in Kilowatt-hours
A kilowatt-hour (kWh) is equal to the energy of 1,000 watts working for one hour. The amount of electricity a power plant generates or a customer uses over a period of time is measured in kilowatt-hours (kWh). Kilowatt-hours are determined by multiplying the number of kilowatts required by the number of hours of use.

For example, if you use a 40-watt light bulb for 5 hours, you have used 200 watt-hours, or 0.2 kilowatt-hours, of electrical energy.


APPLICATION
ELECTRICITY & MAGNETISM
ELECTRONICS
BIOELECTRICITY
ELECTRIC CHARGE
ELECTRIC CIRCUITS
CIRCUIT ELEMENTS
LORENTZ FORCE LAW
COULOMB'S LAW
OHM'S LAW
GAUSS'S LAW
MAGNETIC FIELD
DC CIRCUITS
CURRENT LAW
MAXWELL'S EQUATIONS
ELECTRIC FIELD
CAPACITOR
ELECTRIC POWER
AMPERE'S LAW
VOLTAGE LAW
VOLTAGE
AC CIRCUITS
RESISTOR
BIOT-SAVART LAW
EM WAVES
EMF
ELECTRIC CURRENT
HOUSEHOLD WIRING
INDUCTOR
MEASUREMENT
FARADAY'S LAW

Section 3 – Electrical Principles and Application Section Post Quiz

1. Electric power is the rate at which *electric resistance* is transferred by an electric circuit.
A. True B. False

2. The SI unit of power is the Amp, one joule per second.
A. True B. False

3. Which term is an unit of electrical potential or motive force - potential is required to send one ampere of current through one ohm of resistance?

4. Which term is an unit of resistance?

5. Power Factor - ratio of watts to?

6. Which term is an - units of current?

7. Which term is an unit of electrical energy or power?

8. Which term is a product of volts and amperes as shown by a voltmeter and ammeter - in direct current systems the volt ampere is the same as watts or the energy?

9. According to the text, a Kilovolt Ampere - one kilovolt ampere - ?

10. Kilowatt-hours are determined by multiplying the number of kilowatts required by the number of hours of use.
A. True B. False

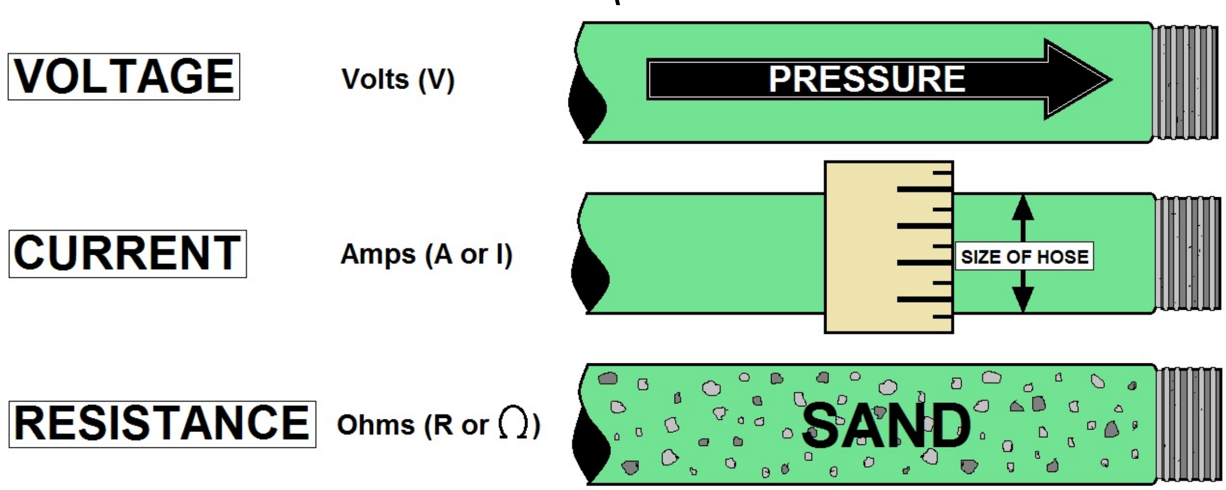
Section 3- Post Quiz Answers

1. False
2. False
3. Volt
4. Ohm
5. Volt amperes
6. Ampere
7. Watt
8. Volt Ampere
9. KVA
10. True

Section 4 – Hydraulic Analogy Principles

Section Focus: You will learn the basics of electrical distribution using water moving terminology. At the end of this section, you will be able to understand and describe simple forms of electrical principles and express these in hydraulic analogy. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: In order to understand electrical principles, we first need to understand the various simple forms of electricity in hydraulic terminology known as hydraulic analogy. Because this area of study is quite large and detailed, we will only focus upon simple electrical and hydraulic principles.

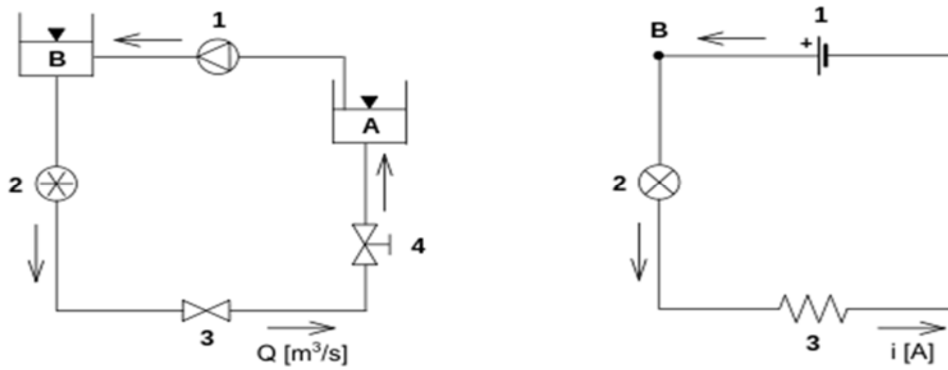


ELECTRICITY TO WATER EXAMPLE

Water (Hydraulic) and Electrical Principles Are Very Similar

The electronic–**hydraulic analogy** (derisively referred to as the **drain-pipe theory** by Oliver Heaviside) is the most widely used analogy for "electron fluid" in a metal conductor. Since electric current is invisible and the processes at play in electronics are often difficult to demonstrate, the various electronic components are represented by hydraulic equivalents.

Electricity (as well as heat) was originally understood to be a kind of fluid, and the names of certain electric quantities (such as current) are derived from hydraulic equivalents. As all analogies, it demands an intuitive and competent understanding of the baseline paradigms (electronics and hydraulics).



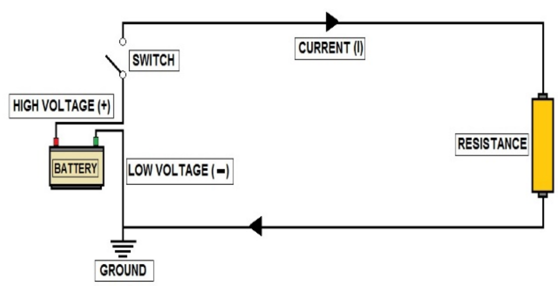
ANALOGY BETWEEN A HYDRAULIC CIRCUIT (LEFT) AND AN ELECTRONIC CIRCUIT (RIGHT).

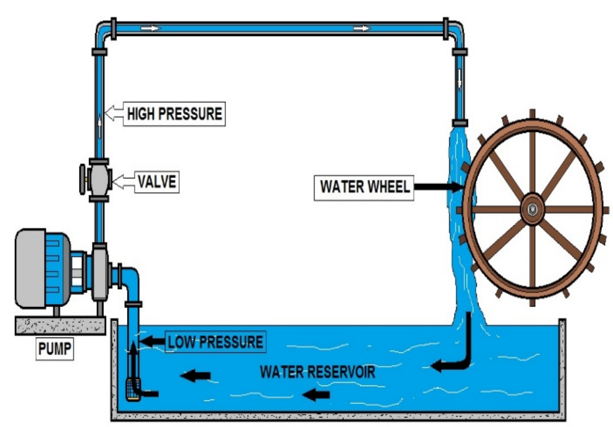
Basic Hydraulic Ideas

There are two basic paradigms:

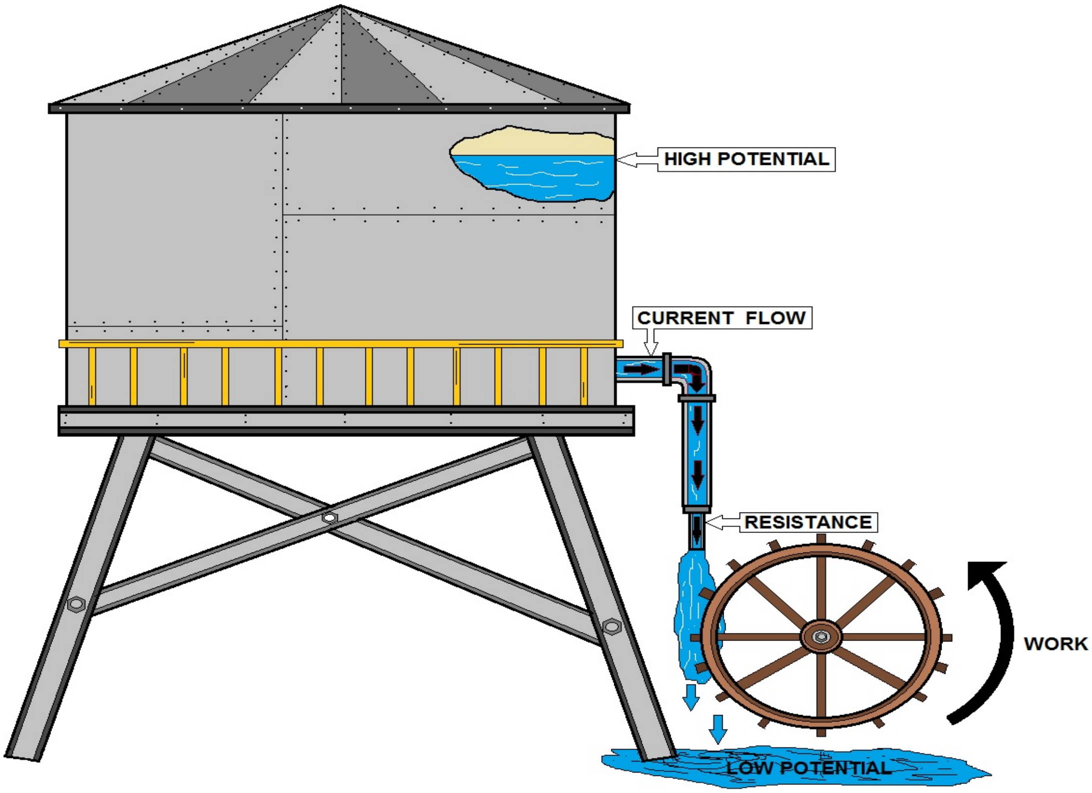
- Version with pressure induced by gravity. Large tanks of water are held up high, or are filled to differing water levels, and the potential energy of the water head is the pressure source. This is reminiscent of electrical diagrams with an up arrow pointing to +V, grounded pins that otherwise are not shown connecting to anything, and so on.
- Completely enclosed version with pumps providing pressure only; no gravity. This is reminiscent of a circuit diagram with a voltage source shown and the wires actually completing a circuit.

Applications: Flow and pressure variables can be calculated in fluid flow network with the use of the hydraulic ohm analogy. The method can be applied to both steady and transient flow situations.

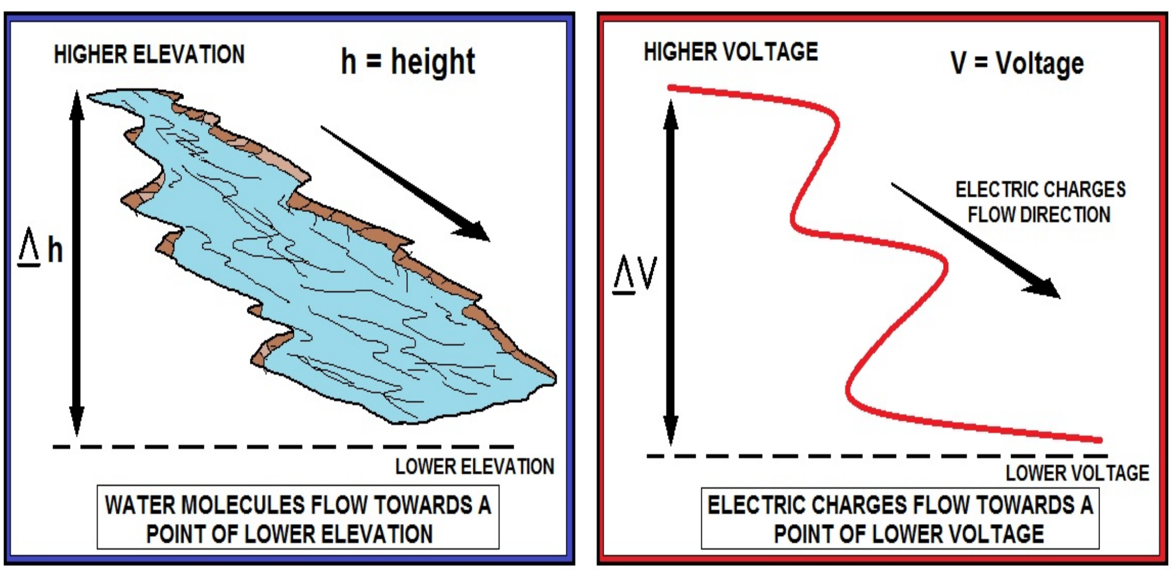




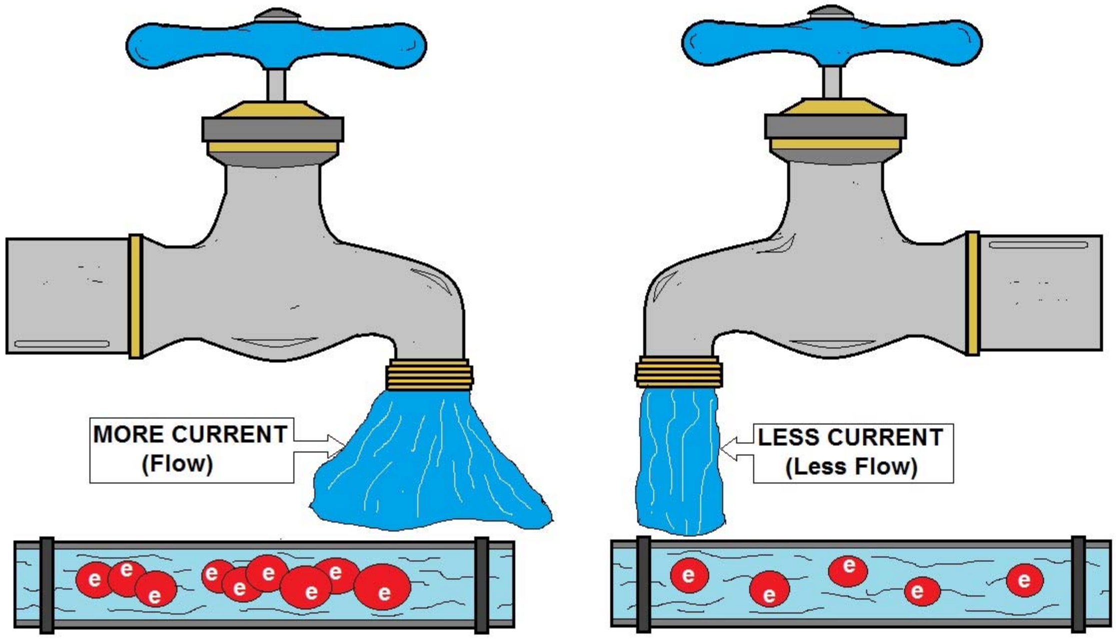
EXAMPLE OF HOW WATER FLOWS SIMILAR TO ELECTRICITY



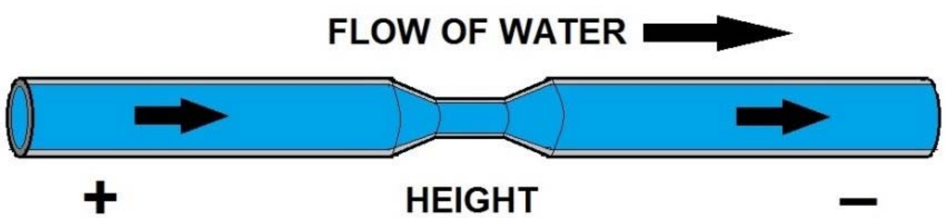
WATER FLOWS LIKE ELECTRICITY



WATER FLOWS LIKE ELECTRICITY EXAMPLE

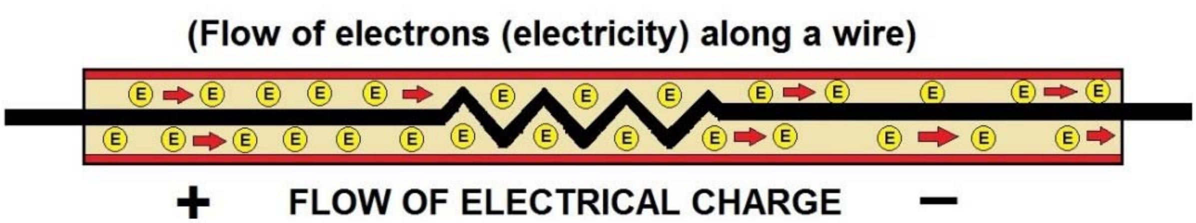


ELECTRIC CURRENT – WATER ANALOGY



Electricity flow can be compared to flow of water:

- When pressure is applied at one end of a pipe (or wire) then, water (or electricity) will come out the other end.



BASIC ELECTRICITY CONCEPT

Hydraulic Component Equivalents

Wires
A relatively wide pipe completely filled with water is equivalent to a piece of wire. When comparing to a piece of wire, the pipe should be thought of as having semi-permanent caps on the ends. Connecting one end of a wire to a circuit is equivalent to forcibly un-capping one end of the pipe and attaching it to another pipe. With few exceptions (such as a high-voltage power source), a wire with only one end attached to a circuit will do nothing; the pipe remains capped on the free end, and thus adds nothing to the circuit.

Electric potential
In general, it is equivalent to hydraulic head. In this article, it is assumed that the water is flowing horizontally, so that the force of gravity can be ignored, and then electric potential is equivalent to pressure.

Voltage
Also called voltage drop or *potential difference*. A difference in pressure between two points. Usually measured in volts.

Electric charge
Equivalent to a quantity of water.

Current
Equivalent to a hydraulic volume flow rate; that is, the volumetric quantity of flowing water over time. Usually measured in amperes.

Ideal voltage source, or ideal battery
A dynamic pump with feedback control. A pressure meter on both sides shows that regardless of the current being produced, this kind of pump produces constant pressure difference. If one terminal is kept fixed at ground, another analogy is a large body of water at a high elevation, sufficiently large that the drawn water does not affect the water level.

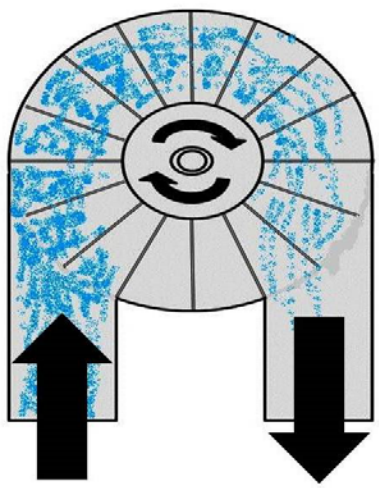
Ideal current source
A positive displacement pump. A current meter (little paddle wheel) shows that when this kind of pump is driven at a constant speed, it maintains a constant speed of the little paddle wheel.

Resistor
A constriction in the bore of the pipe which requires more pressure to pass the same amount of water. All pipes have some resistance to flow, just as all wires have some resistance to current.

Capacitor
A tank with one connection at each end and a rubber sheet dividing the tank in two lengthwise (a hydraulic accumulator). When water is forced into one pipe, equal water is simultaneously forced out the other pipe, yet no water can penetrate the rubber diaphragm. Energy is stored by the stretching of the rubber. As more current flows "through" the capacitor, the back-pressure (voltage) becomes greater, thus current "leads" voltage in a capacitor. As the back-pressure from the stretched rubber approaches the applied pressure, the current becomes less and less. Thus capacitors "filter out" constant pressure differences and slowly varying, low-frequency pressure differences, while allowing rapid changes in pressure to pass through.

Note that the device described will pass all changes in pressure "through" equally well, regardless of rate of change, just as an electrical capacitor will. Any device in series must obey (electrical) Kirchhoff's Current Law, or its hydraulic equivalent. Considering the "filter" action, a better and more exact analogy is the hydraulic accumulator "pressure tank", as described, but with a closed, pressurized air bladder and only one water connection. Such accumulators are commonly used in hydraulic power systems exactly for the purpose of damping out pressure surges and "hammers" due to valves opening and closing.

Inductor
A heavy paddle wheel placed in the current. The mass of the wheel and the size of the blades restrict the water's ability to rapidly change its rate of flow (current) through the wheel due to the effects of inertia, but, given time, a constant flowing stream will pass mostly unimpeded through the wheel, as it turns at the same speed as the water flow. The mass and surface area of the wheel and its blades are analogous to inductance, and friction between its axle and the axle bearings corresponds to the resistance that accompanies any non-superconducting inductor.



TURBINE INDUCTOR PADDLE

Inductors are analogous to a heavy paddle wheel/turbine placed in the current.

An alternative inductor model is simply a long pipe, perhaps coiled into a spiral for convenience. This fluid-inertia device is used in real life as an essential component of a hydraulic ram. The inertia of the water flowing through the pipe produces the inductance effect; inductors "filter out" rapid changes in flow, while allowing slow variations in current to be passed through. The drag imposed by the walls of the pipe is somewhat analogous to parasitic resistance.

In either model, the pressure difference (voltage) across the device must be present before the current will start moving, thus in inductors voltage "leads" current. As the current increases, approaching the limits imposed by its own internal friction and of the current that the rest of the circuit can provide, the pressure drop across the device becomes lower and lower.

Diode
Equivalent to a one-way check valve with a slightly leaky valve seat. As with a diode, a small pressure difference is needed before the valve opens. And like a diode, too much reverse bias can damage or destroy the valve assembly.

Transistor
A valve in which a diaphragm, controlled by a low-current signal (either constant current for a BJT or constant pressure for a FET), moves a plunger which affects the current through another section of pipe.

CMOS
A combination of two MOSFET transistors. As the input pressure changes, the pistons allow the output to connect to either zero or positive pressure.

Memristor
A needle valve operated by a flow meter. As water flows through in the forward direction, the needle valve restricts flow more; as water flows the other direction, the needle valve opens further providing less resistance.

Hydraulic - Electrical Principle Equivalents

EM Wave Speed (velocity of propagation)
Speed of sound in water. When a light switch is flipped, the electric wave travels very quickly through the wires.

Charge Flow Speed (drift velocity)
Particle speed of water. The moving charges themselves move rather slowly.

DC
Constant flow of water in a circuit of pipe.

Low Frequency AC
Water oscillating back and forth in a pipe.

Higher-Frequency AC and Transmission Lines
Sound being transmitted through the water pipes: Be aware that this does not properly mirror the cyclical reversal of alternating electric current. As described, the fluid flow conveys pressure fluctuations, but fluids “do not” reverse at high rates in hydraulic systems, which the above "low frequency" entry does accurately describe. A better concept (if sound waves are to be the phenomenon) is that of direct current with high-frequency "ripple" superimposed.

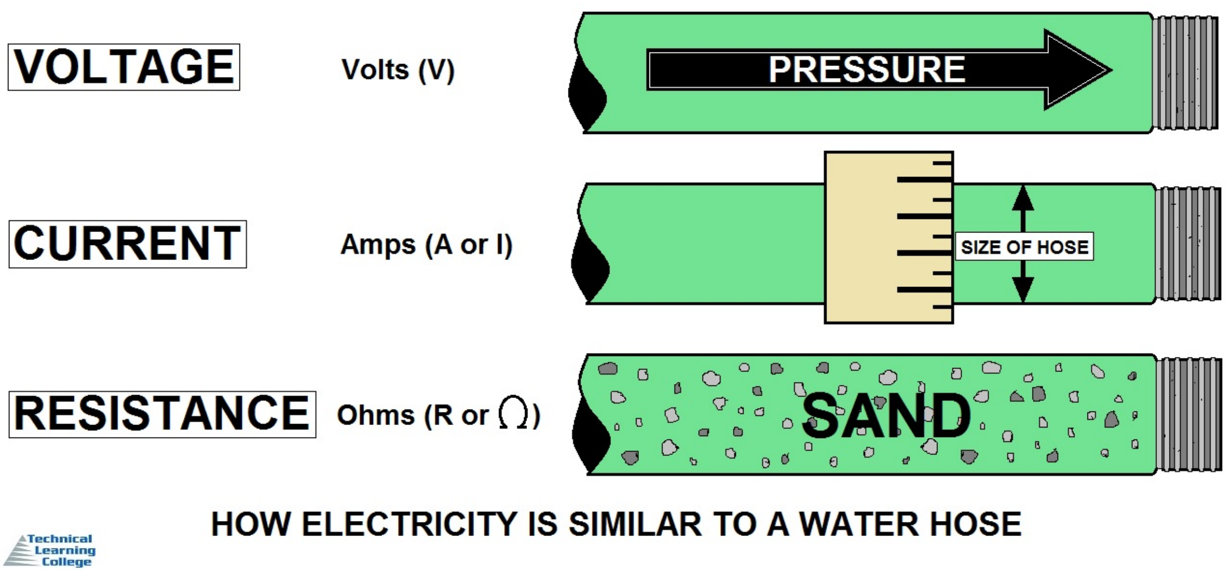
Inductive Spark
Used in induction coils, similar to water hammer, caused by the inertia of water.

Hydraulic Equation Examples

Some examples of equivalent electrical and hydraulic equations:

type	hydraulic	electric	thermal	mechanical
quantity	volume V [m³]	charge q [C]	heat Q [J]	momentum P [Ns]
potential	pressure P [Pa=J/m³]	potential ϕ [V=J/C]	temperature T [K=J/k_B]	velocity v [m/s]
flux	Volumetric flow rate Φ_V [m³/s]	current I [A=C/s]	heat transfer rate $\dot{Q}$ [J/s]	force F [N]
flux density	velocity v [m/s]	current density j [C/(m²·s) = A/m²]	heat flux $\dot{Q}''$ [W/m²]	stress σ [N/m² = Pa]
linear model	Poiseuille's law $\Phi_V = \frac{\pi r^4}{8\eta}\frac{\Delta p^\star}{\ell}$	Ohm's law $j = -\sigma\nabla\phi$	Fourier's law $\dot{Q}'' = \kappa\nabla T$	Dashpot $\sigma = c\Delta v$

If the differential equations have the same form, the response will be similar.



HOW ELECTRICITY IS SIMILAR TO A WATER HOSE

Limits to the Hydraulic Analogy

If taken too far, the water analogy can create misconceptions. For it to be useful, we must remain aware of the regions where electricity and water behave very differently.

Fields (Maxwell equations, Inductance)
Electrons can push or pull other distant electrons via their fields, while water molecules experience forces only from direct contact with other molecules. For this reason, waves in water travel at the speed of sound, but waves in a sea of charge will travel much faster as the forces from one electron are applied to many distant electrons and not to only the neighbors in direct contact. In a hydraulic transmission line, the energy flows as mechanical waves through the water, but in an electric transmission line the energy flows as fields in the space surrounding the wires, and does not flow inside the metal. Also, an accelerating electron will drag its neighbors along while attracting them, both because of magnetic forces.

Charge
Unlike water, movable charge carriers can be positive or negative, and conductors can exhibit an overall positive or negative net charge. The mobile carriers in electric currents are usually electrons, but sometimes they are charged positively, such as H^+ ions in proton conductors or holes in p-type semiconductors and some (very rare) conductors.

Leaking Pipes
The electric charge of an electrical circuit and its elements is usually almost equal to zero, hence it is (almost) constant. This is formalized in Kirchhoff's current law, which does not have an analogy to hydraulic systems, where amount of the liquid is not usually constant. Even with incompressible liquid the system may contain such elements as pistons and open pools, so the volume of liquid contained in a part of the system can change. For this reason, continuing electric currents require closed loops rather than hydraulics' open source/sink resembling spigots and buckets.

> **James Thurber spoke of his maternal grandmother thus:**
> *She came naturally by her confused and groundless fears, for her own mother lived the latter years of her life in the horrible suspicion that electricity was dripping invisibly all over the house. - My Life and Hard Times (1933).*

Fluid Velocity and Resistance of Metals
As with water hoses, the carrier drift velocity in conductors is directly proportional to current. However, water only experiences drag via the pipes' inner surface, while charges are slowed at all points within a metal. Also, typical velocity of charge carriers within a conductor is less than centimeters per minute, and the "electrical friction" is extremely high. If charges ever flowed as fast as water can flow in pipes, the electric current would be immense, and the conductors would become incandescently hot and perhaps vaporize.

To model the resistance and the charge-velocity of metals, perhaps a pipe packed with sponge, or a narrow straw filled with syrup, would be a better analogy than a large-diameter water pipe. Resistance in most electrical conductors is a linear function: as current increases, voltage drop increases proportionally (Ohm's Law). Liquid resistance in pipes is not linear with volume, varying as the square of volumetric flow (see Darcy–Weisbach equation).

Quantum Mechanics
Conductors and insulators contain charges at more than one discrete level of atomic orbit energy, while the water in one region of a pipe can only have a single value of pressure. For this reason there is no hydraulic explanation for such things as a battery's charge pumping ability, a diode's voltage drop, solar cell functions, Peltier effect, etc., however equivalent devices can be designed which exhibit similar responses, although some of the mechanisms would only serve to regulate the flow curves rather than to contribute to the component's primary function.

Usefulness requires that the reader or student has a substantial understanding of the model (hydraulic) system's principles. It also requires that the principles can be transferred to the target (electrical) system. Hydraulic systems are deceptively simple: the phenomenon of pump cavitation is a known, complex problem that few people outside of the fluid power or irrigation industries would understand. For those who do, the hydraulic analogy is amusing, as no "cavitation" equivalent exists in electrical engineering. The hydraulic analogy can give a mistaken sense of understanding that will be exposed once a detailed description of electrical circuit theory is required.

One must also consider the difficulties in trying to make the analogy work. The above "electrical friction" example, where the hydraulic analog is a pipe filled with sponge material, illustrates the problem: the model must be increased in complexity beyond any realistic scenario.

Electrical Measurements and Equipment

Molecule of liquid → electron of electricity

Flow rate (gpm) → current (ampere) I, A

Pressure (psi) → potential (V)

Pressure drop → voltage drop

Pump → generator

Section 4–Hydraulic Analogy Principles Post Quiz

1. If water is flowing horizontally, so that the force of gravity can be ignored, and then electric potential is equivalent to?

2. Electric potential: In general, it is equivalent to static energy.
A. True B. False

3. When comparing to a piece of wire, a water pipe should be thought of as having no caps on the ends.
A. True B. False

4. Memristor is a needle valve operated by a flow meter.
A. True B. False

5. Connecting one end of a wire to a circuit is equivalent to forcibly un-capping one end of the pipe and attaching it to another pipe.
A. True B. False

6. In hydraulic terms, a Memristor, as water flows through in the forward direction, the needle valve restricts flow more; as water flows the other direction, ____________opens further providing less resistance.

7. In hydraulic terms, a Capacitor is a water tank with one connection at each end and a rubber sheet dividing the tank in two lengthwise.
A. True B. False

8. CMOS: A combination of two MOSFET transistors. As the input pressure changes, the pistons allow the output to connect to?

9. In a Capacitor when water is forced into one pipe, equal water is simultaneously forced out the other pipe, yet no water can penetrate the rubber diaphragm, energy is stored by the?

10. As more current flows "through" the capacitor, the back-pressure becomes greater, thus current "leads"?

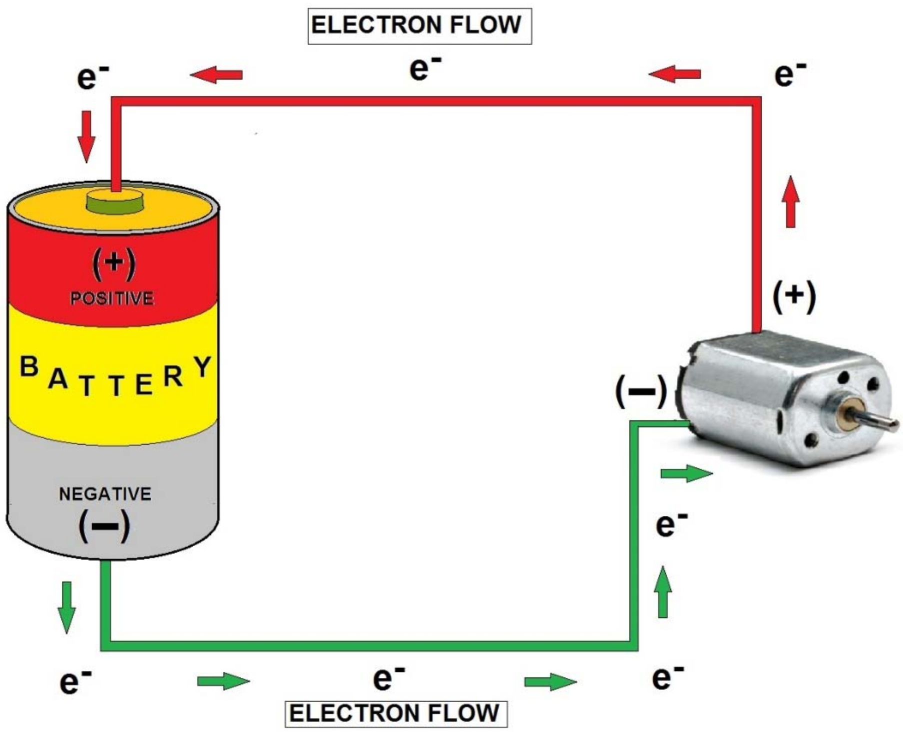
Section 4 Post Quiz Answers

1. Pressure
2. True
3. False
4. True
5. True
6. The needle valve
7. True
8. Either zero or positive pressure
9. Stretching of the rubber
10. Voltage in a capacitor

Section 5 – Electrical Laws and Theories

Section Focus: You will learn the basics of electrical theories and laws. At the end of this section, you will be able to understand and describe simple electrical laws and theories. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: In order to understand electrical principles, we first need to explain the various simple forms of electricity in scientific laws and theories. Because this area of study is quite large and detailed, we will only focus upon simple electrical laws and theories.



EXAMPLE OF DIRECT CURRENT

Electrical Theory

History

Henry Cavendish and the First Electric Meter

In 1799, Cavendish designed an investigation to qualitatively describe the conductivity of different metals. He used a very simple technique by discharging an electrical apparatus through a wire to his own body. Cavendish rotated a frictional generator with a fixed number of turns to produce the same amount of charge for each trial, and he was able to correctly order the conductivity of the metals by the intensity of shock he received from the generator. Cavendish, whose results were never published in his time, was qualitatively comparing the resistance of different materials to the effects of current.

This type of qualitative analysis was an entertaining pastime in some 18th-century kitchens and parlors—small boys and women have been depicted in paintings passing shocks from electrostatic machines through the familiar "human chain" of resistance. In addition to the obvious risk, resistance, from the earliest times, was demonstrated to be dependent on the length of the conductor. In addition, the spark gap and physiological shock could be related to the intensity of the charge distribution.

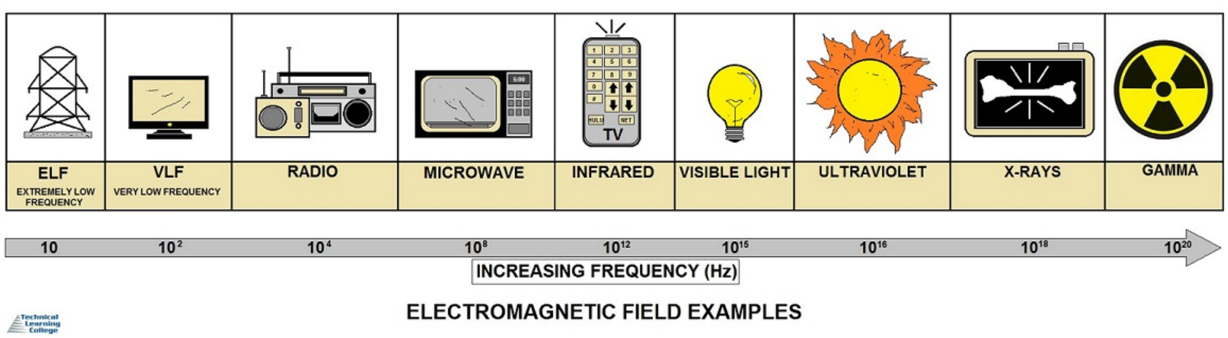
For example, consider a sphere charged by a fixed number of turns. When discharged, it could produce a spark across a measurable gap. If we use a smaller sphere charged with the same number of turns, we observe that the spark jumps a larger gap. In other words, the same quantity of charge in a smaller volume has a greater "intensity."

This intensity, or "tension," could be more accurately measured by an electroscope and, after Volta's invention of the electric pile in 1800; attempts were made to relate static electricity with other types of electricity.

Volta's battery marks a significant conceptual change in our understanding of the electrical phenomenon.

The battery remains inactive until an external conductor provides a path through which the electricity is conveyed. Thus, it became imperative to reveal the characteristics and influence of the external conductor. However, at this time, no instrument (other than human sensation) existed that could measure or ascertain the phenomena associated with the conductor.

Fortunately, Cavendish's role as a human meter was no longer necessary by 1820 with Ørsted's discovery of the deflection of a compass needle by an electric current. Shortly afterwards, Schweigger used a coil to pass a current repeatedly over a compass to fabricate a more sensitive instrument to detect and compare the electromagnetic effects of various currents.



ELECTROMAGNETIC FIELD EXAMPLES

The Tangent Galvanometer

The first reference to a tangent galvanometer appeared in an 1837paper by Claude Servais Mathias Pouillet (1790–1868). Pouillet used the tangent galvanometer to investigate Ohm's Law and later, James Joule, in 1841, immersed different lengths of wire into cylinders of water to investigate the relationship between the rate of heat dissipation and current.

The tangent galvanometer was modified by Hermann von Helmholtz (1821–94) in 1849.

He suggested that two, identical, current-carrying coils be placed parallel to each other to form the arrangement now known as Helmholtz coils. In this arrangement the magnetic field is essentially uniform.

To measure current, Joule used a tangent galvanometer, which was aligned with the North-South meridian such that the magnetic field of the coil was perpendicular to the magnetic field of the Earth. The deflection of the compass needle is the vector sum of the magnetic effects of the Earth and the field of the loop.

Therefore,

$$\tan \emptyset = \frac{B\ loop}{B\ earth}$$

Since B_{earth} is constant, it follows that tan θ α B_{loop}. By increasing the number of loops, and therefore the current past any given point, we can also establish that I α B_{loop}, and therefore tan θ α I and tan θ can be used as a measure of current.

Joule's tangent galvanometer proved to be a reliable measure of current, which we can still use today. The use of a tangent galvanometer has the additional advantage of providing an evidential base for the modern galvanometer and ammeter.

Understanding Voltage - Introduction

Voltage, **electrical potential difference**, **electric tension** or **electric pressure** (denoted ΔV) and measured in units of electric potential: volts, or joules per coulomb is the electric potential difference between two points, or the difference in electric potential energy of a unit charge transported between two points.

Voltage is equal to the work done per unit charge against a static electric field to move the charge between two points. A voltage may represent either a source of energy (electromotive force), or lost, used, or stored energy (potential drop). A voltmeter can be used to measure the voltage (or potential difference) between two points in a system; usually a common reference potential such as the ground of the system is used as one of the points. Voltage can be caused by static electric fields, by electric current through a magnetic field, by time-varying magnetic fields, or some combination of these three.

Given two points in the space, called A and B, voltage is the difference of electric potentials between those two points. From the definition of electric potential it follows that:

$$\Delta V_{BA} = V_B - V_A = -\int_{r0}^{B} \vec{E} \cdot d\vec{l} - \left(-\int_{r0}^{A} \vec{E} \cdot d\vec{l} \right)$$
$$= \int_{B}^{r0} \vec{E} \cdot d\vec{l} + \int_{r0}^{A} \vec{E} \cdot d\vec{l} = \int_{B}^{A} \vec{E} \cdot d\vec{l}$$

Voltage is electric potential energy per unit charge, measured in joules per coulomb (= volts). It is often referred to as "electric potential", which then must be distinguished from electric potential energy by noting that the "potential" is a "per-unit-charge" quantity.

Like mechanical potential energy, the zero of potential can be chosen at any point, so the difference in voltage is the quantity which is physically meaningful. The difference in voltage measured when moving from point A to point B is equal to the work which would have to be done, per unit charge, against the electric field to move the charge from A to B. The voltage between the two ends of a path is the total energy required to move a small electric charge along that path, divided by the magnitude of the charge.

Mathematically this is expressed as the line integral of the electric field and the time rate of change of magnetic field along that path. In the general case, both a static (unchanging) electric field and a dynamic (time-varying) electromagnetic field must be included in determining the voltage between two points.

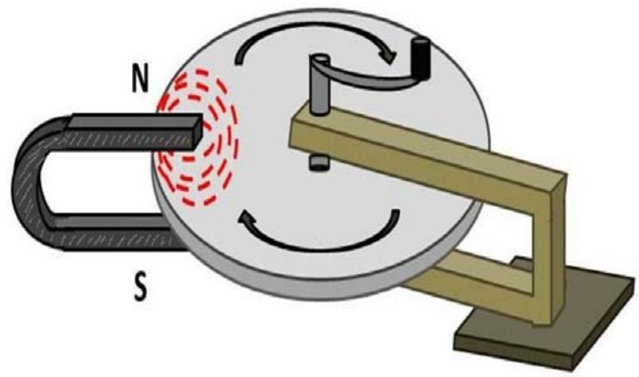
Historically this quantity has also been called "tension" and "pressure". Pressure is now obsolete but tension is still used, for example within the phrase "high tension" (HT) which is commonly used in thermionic valve (vacuum tube) based electronics.

Voltage is defined so that negatively charged objects are pulled towards higher voltages, while positively charged objects are pulled towards lower voltages. Therefore, the conventional current in a wire or resistor always flows from higher voltage to lower voltage.

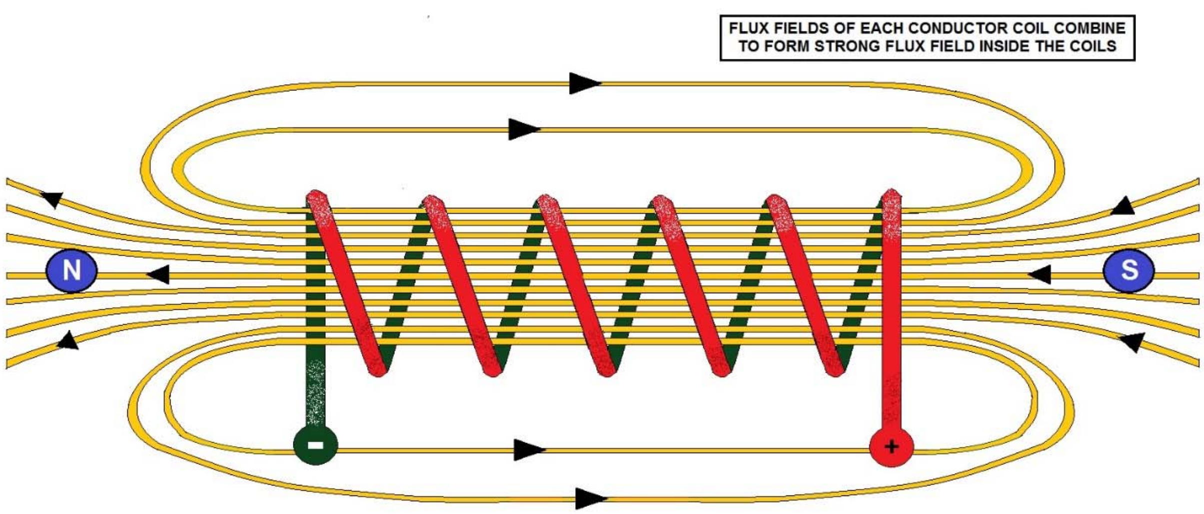
Current can flow from lower voltage to higher voltage, but only when a source of energy is present to "push" it against the opposing electric field. For example, inside a battery, chemical reactions provide the energy needed for current to flow from the negative to the positive terminal.

Technically, in a material the electric field is not the only factor determining charge flow, and different materials naturally develop electric potential differences at equilibrium (Galvani potentials). The electric potential of a material is not even a well-defined quantity, since it varies on the subatomic scale.

A more convenient definition of 'voltage' can be found instead in the concept of Fermi level. In this case the voltage between two bodies is the thermodynamic work required to move a unit of charge between them. This definition is practical since a real voltmeter actually measures this work, not differences in electric potential.



FARADAY'S DISC



ELECTROMAGNETISM IN A DISC

Faraday's Law

MICHAEL FARADAY

Any change in the magnetic environment of a coil of wire will cause a voltage (EMF) to be "induced" in the coil. No matter how the change is produced, the voltage will be generated. The change could be produced by changing the magnetic field strength, moving a magnet toward or away from the coil, moving the coil into or out of the magnetic field, rotating the coil relative to the magnet, etc.

$$EMF = -\frac{d\Phi}{dt}$$

$$\int_S \nabla \times \mathbf{E} \cdot \mathbf{dS} = -\frac{d}{dt}\int_S \mathbf{B}(t) \cdot \mathbf{dS} = \int_S \frac{-d\mathbf{B}(t)}{dt} \cdot \mathbf{dS}$$

$$\Rightarrow \boxed{\nabla \times \mathbf{E} = \frac{-\partial \mathbf{B}(t)}{\partial t}}$$

Lenz's Law
When an EMF is generated by a change in magnetic flux according to Faraday's Law, the polarity of the induced emf is such that it produces a current whose magnetic field opposes the change which produces it. The induced magnetic field inside any loop of wire always acts to keep the magnetic flux in the loop constant. In the examples below, if the B field is increasing, the induced field acts in opposition to it. If it is decreasing, the induced field acts in the direction of the applied field to try to keep it constant.

Magnet and Coil
When a magnet is moved into a coil of wire, changing the magnetic field and magnetic flux through the coil, a voltage will be generated in the coil according to Faraday's Law. When the magnet is moved into the coil the galvanometer deflects to the left in response to the increasing field. When the magnet is pulled back out, the galvanometer deflects to the right in response to the decreasing field. The polarity of the induced EMF is such that it produces a current whose magnetic field opposes the change that produces it. The induced magnetic field inside any loop of wire always acts to keep the magnetic flux in the loop constant. This inherent behavior of generated magnetic fields is summarized in Lenz's Law.

Back to Faraday's Law
The most widespread version of Faraday's law states:
The induced electromotive force in any closed circuit is equal to the negative of the time rate of change of the magnetic flux through the circuit.

This version of Faraday's law strictly holds only when the closed circuit is a loop of infinitely thin wire, and is invalid in other circumstances as discussed below.

Quantitative

The definition of surface integral relies on splitting the surface Σ into small surface elements. Each element is associated with a vector $d\mathbf{A}$ of magnitude equal to the area of the element and with direction normal to the element and pointing “outward” (with respect to the orientation of the surface).

Faraday's law of induction makes use of the magnetic flux Φ_B through a hypothetical surface Σ whose boundary is a wire loop. Since the wire loop may be moving, we write Σ(*t*) for the surface. The magnetic flux is defined by a surface integral:

$$\Phi_B = \iint\limits_{\Sigma(t)} \mathbf{B}(\mathbf{r}, t) \cdot d\mathbf{A} \ ,$$

where *d***A** is an element of surface area of the moving surface Σ(*t*), **B** is the magnetic field, and **B**·*d***A** is a vector dot product (the infinitesimal amount of magnetic flux). In more visual terms, the magnetic flux through the wire loop is proportional to the number of magnetic flux lines that pass through the loop.

When the flux changes—because **B** changes, or because the wire loop is moved or deformed, or both—Faraday's law of induction says that the wire loop acquires an EMF, $\mathcal{E}$, defined as the energy available from a unit charge that has travelled once around the wire loop. Equivalently, it is the voltage that would be measured by cutting the wire to create an open circuit, and attaching a voltmeter to the leads. According to the Lorentz force law (in SI units),

$$\mathbf{F} = q\left(\mathbf{E} + \mathbf{v} \times \mathbf{B}\right)$$

the EMF on a wire loop is:

$$\mathcal{E} = \frac{1}{q} \oint_{\mathrm{wire}} \mathbf{F} \cdot d\boldsymbol{\ell} = \oint_{\mathrm{wire}} \left(\mathbf{E} + \mathbf{v} \times \mathbf{B}\right) \cdot d\boldsymbol{\ell}$$

where **E** is the electric field, **B** is the magnetic field (aka magnetic flux density, magnetic induction), d***ℓ*** is an infinitesimal arc length along the wire, and the line integral is evaluated along the wire (along the curve the coincident with the shape of the wire).

The EMF is also given by the rate of change of the magnetic flux:

$$\mathcal{E} = -\frac{d\Phi_B}{dt} \ ,$$

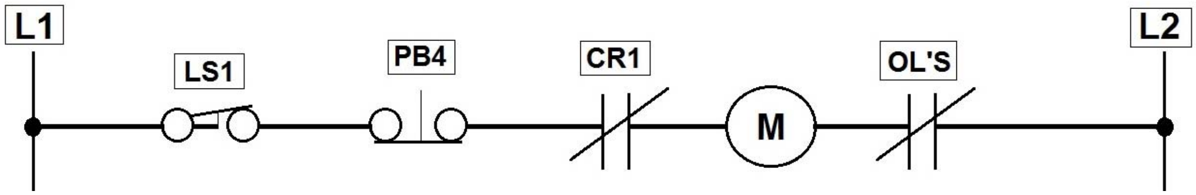
where $\mathcal{E}$ is the electromotive force (EMF) in volts and Φ_B is the magnetic flux in webers. The direction of the electromotive force is given by Lenz's law.

For a tightly wound coil of wire, composed of *N* identical turns, each with the same Φ_B,

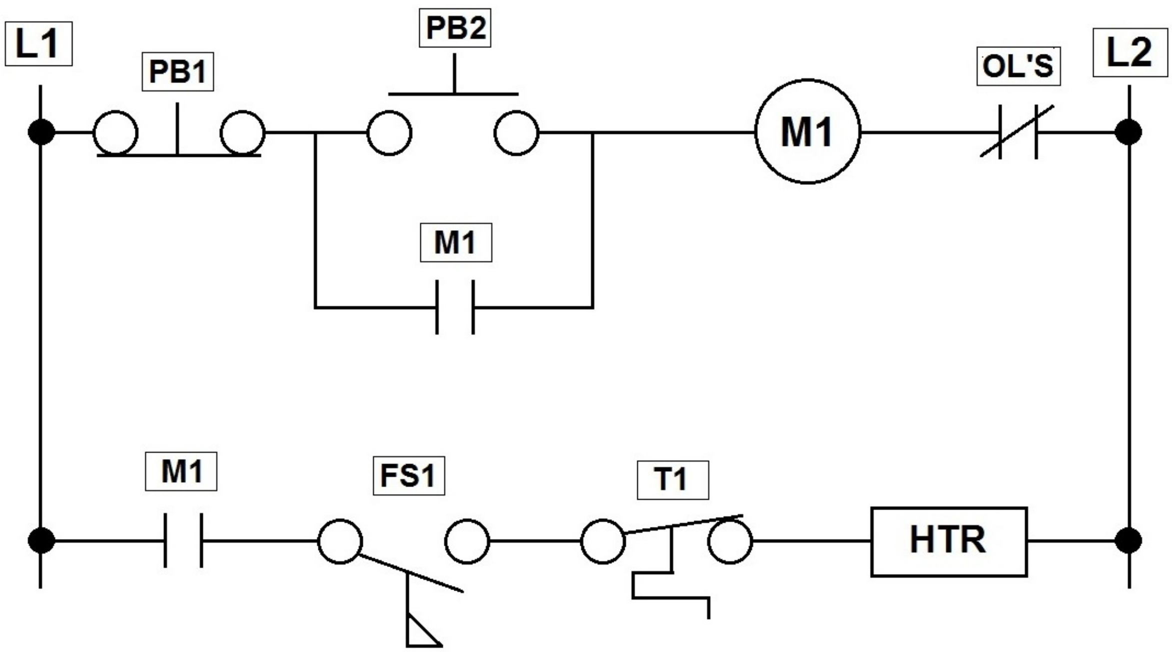
Faraday's law of induction states that

$$\mathcal{E} = -N \frac{d\Phi_B}{dt}$$

where *N* is the number of turns of wire and Φ_B is the magnetic flux in webers through a *single* loop.



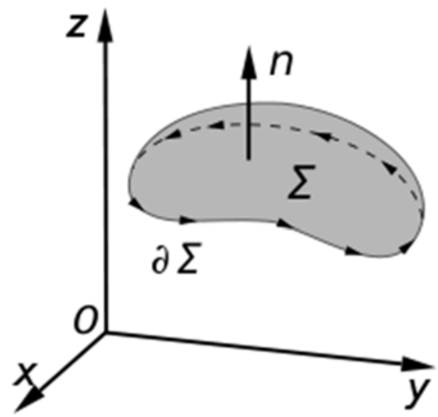
1. Control voltage is 120 volts. Assume that an overload on the motor has tripped.
What voltage would you expect to find across coil M (point A to point 8) in this circuit? What would points A and B read to ground?



In the circuit above, the blower motor runs but the heater does not work. What would you test first?
A. the resistance of the M1 contacts on the rung with the heater.
B. the current in the line to the heater with the motor running.
C. the voltage on the T1 side of the heater with the motor running.
D. the voltage between FS1 and T1 with the motor stopped.

2. In the above circuit the problem is that the heater always turns on at the same time as the motor, except when the heater is up to temperature. The cause must be:
A. contacts M 1 are closing too soon.
B. FS1 is stuck closed.
C. T1 is misadjusted.
D. contacts M1 are opening when FS1 activates.

Maxwell–Faraday Equation



An illustration of Kelvin-Stokes theorem with surface **Σ** its boundary ***∂Σ*** and orientation ***n*** set by the right-hand rule.

The Maxwell–Faraday equation is a generalization of Faraday's law that states that a time-varying magnetic field is always accompanied by a spatially-varying, non-conservative electric field, and vice-versa.

The Maxwell–Faraday equation is

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

(in SI units) where $\nabla \times$ is the curl operator and again **E**(**r**, *t*) is the electric field and **B**(**r**, *t*) is the magnetic field. These fields can generally be functions of position **r** and time *t*.

The Maxwell–Faraday equation is one of the four Maxwell's equations, and therefore plays a fundamental role in the theory of classical electromagnetism. It can also be written in an **integral form** by the Kelvin-Stokes theorem:

$$\oint_{\partial \Sigma} \mathbf{E} \cdot d\boldsymbol{\ell} = -\int_{\Sigma} \frac{\partial \mathbf{B}}{\partial t} \cdot d\mathbf{A}$$

where, as indicated in the figure:

- **Σ** is a surface bounded by the closed contour ***∂Σ***,
- **E** is the electric field, **B** is the magnetic field.
- d***ℓ*** is an infinitesimal vector element of the contour ***∂Σ***,
- d**A** is an infinitesimal vector element of surface **Σ**. If its direction is orthogonal to that surface patch, the magnitude is the area of an infinitesimal patch of surface.

Both d**ℓ** and d**A** have a sign ambiguity; to get the correct sign, the right-hand rule is used, as explained in the article Kelvin-Stokes theorem. For a planar surface Σ, a positive path element *d***ℓ** of curve ∂Σ is defined by the right-hand rule as one that points with the fingers of the right hand when the thumb points in the direction of the normal **n** to the surface Σ.

The integral around ***∂*Σ** is called a *path integral* or *line integral*.

Notice that a nonzero path integral for **E** is different from the behavior of the electric field generated by charges. A charge-generated **E**-field can be expressed as the gradient of a scalar field that is a solution to Poisson's equation, and has a zero path integral. See gradient theorem.

The integral equation is true for *any* path ***∂*Σ** through space, and any surface **Σ** for which that path is a boundary.

If the path **Σ** is not changing in time, the equation can be rewritten:

$$\oint_{\partial\Sigma} \mathbf{E} \cdot d\boldsymbol{\ell} = -\frac{d}{dt} \int_{\Sigma} \mathbf{B} \cdot d\mathbf{A}.$$

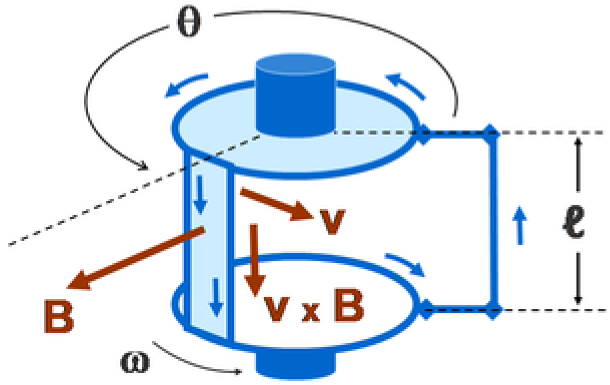
The surface integral at the right-hand side is the explicit expression for the magnetic flux Φ_B through **Σ**.

Faraday Applications

The principles of electromagnetic induction are applied in many devices and systems, including:

- Current clamp
- Electrical generators
- Electromagnetic forming
- Graphics tablet
- Hall effect meters
- Induction cookers
- Induction motors
- Induction sealing
- Induction welding
- Inductive charging
- Inductors
- Magnetic flow meters
- Mechanically powered flashlight
- Pickups
- Rowland ring
- Transcranial magnetic stimulation
- Transformers
- Wireless energy transfer

Electrical Generator Operation



Rectangular wire loop rotating at angular velocity ω in radially outward pointing magnetic field **B** of fixed magnitude. The circuit is completed by brushes making sliding contact with top and bottom discs, which have conducting rims. This is a simplified version of the *drum generator.*

The EMF generated by Faraday's law of induction due to relative movement of a circuit and a magnetic field is the phenomenon underlying electrical generators. When a permanent magnet is moved relative to a conductor, or vice versa, an electromotive force is created. If the wire is connected through an electrical load, current will flow, and thus electrical energy is generated, converting the mechanical energy of motion to electrical energy.

In the Faraday's disc example, the disc is rotated in a uniform magnetic field perpendicular to the disc, causing a current to flow in the radial arm due to the Lorentz force. It is interesting to understand how it arises that mechanical work is necessary to drive this current. When the generated current flows through the conducting rim, a magnetic field is generated by this current through Ampère's circuital law. The rim thus becomes an electromagnet that resists rotation of the disc (an example of Lenz's law).

The return current flows from the rotating arm through the far side of the rim to the bottom brush. The B-field induced by this return current opposes the applied B-field, tending to *decrease* the flux through that side of the circuit, opposing the *increase* in flux due to rotation.

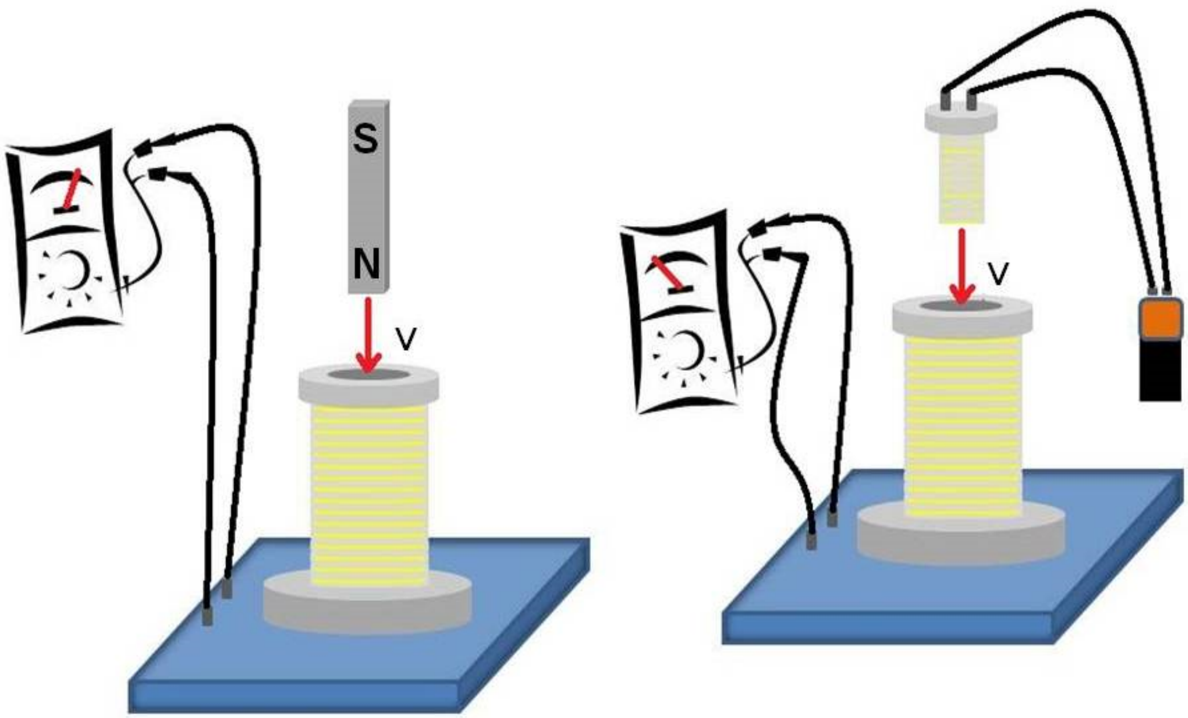
On the near side of the figure, the return current flows from the rotating arm through the near side of the rim to the bottom brush. The induced B-field *increases* the flux on this side of the circuit, opposing the *decrease* in flux due to rotation. Thus, both sides of the circuit generate an EMF opposing the rotation. The energy required to keep the disc moving, despite this reactive force, is exactly equal to the electrical energy generated (plus energy wasted due to friction, Joule heating, and other inefficiencies). This behavior is common to all generators converting mechanical energy to electrical energy.

Electrical Transformer
The EMF predicted by Faraday's law is also responsible for electrical transformers. When the electric current in a loop of wire changes, the changing current creates a changing magnetic field. A second wire in reach of this magnetic field will experience this change in magnetic field as a change in its coupled magnetic flux, $d\,\Phi_B / d\,t$. Therefore, an electromotive force is set up in the second loop called the **induced EMF** or **transformer EMF**. If the two ends of this loop are connected through an electrical load, current will flow.

Magnetic Flow Meter
Faraday's law is used for measuring the flow of electrically conductive liquids and slurries. Such instruments are called magnetic flow meters. The induced voltage ℰ generated in the magnetic field *B* due to a conductive liquid moving at velocity *v* is thus given by:

$$\mathcal{E} = -B\ell v,$$

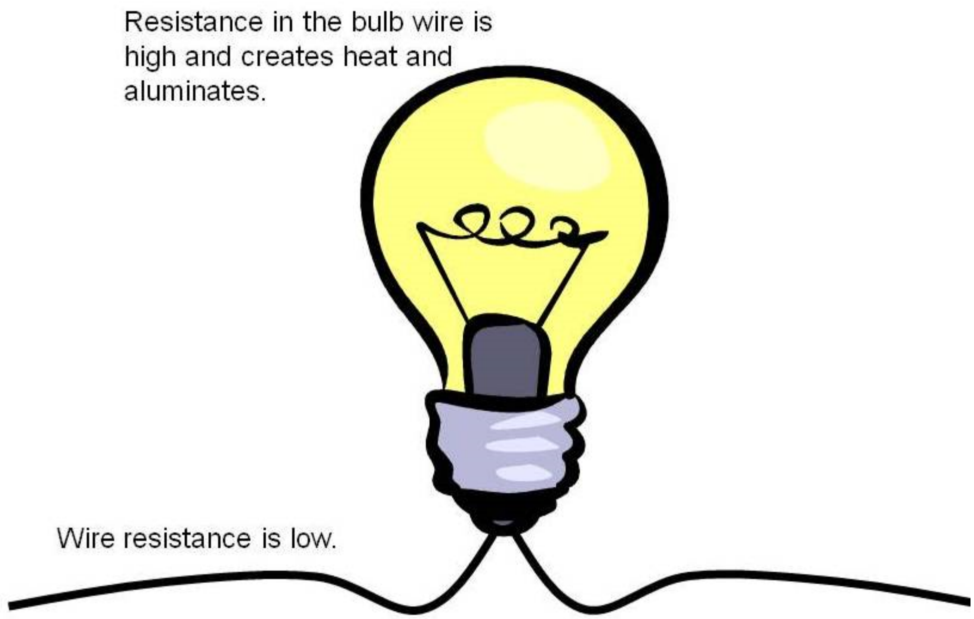
where ℓ is the distance between electrodes in the magnetic flow meter.



FARADAY'S EXPERIEMENT

Understanding Resistance

Except in special superconductor materials, electrons generally do not freely flow. In insulators, like certain ceramics and plastics, electrons are bound tightly to their atoms. No electrons move at all until the voltage or EMF is very high, typically thousands of volts. This is why insulators are used to contain electricity safely. In any conductor, the slightest voltage will move electrons. In those materials with high resistance. However, few will move. In materials with low resistance, many electrons will move with very small voltages.

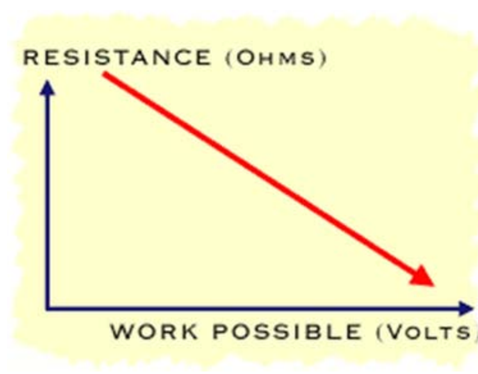


ELECTRICAL RESISTANCE EXAMPLE

*Resistance is measured in Ohms and is designated by the symbol Ω (omega).

Measuring Resistance

The symbol "V" is used to represent something called the **potential difference**. Potential difference is the amount of work done in moving a charge between two points, divided by the size of the charge. That's kind of complicated, though. You can think of potential as electrical height. High potential (near positive charge) is kind of like being on top of a hill. Low potential (near negative charge) is kind of like being in a valley. So potential difference indicates the difference in electrical height between two points. The greater that difference, the more likely it is that charge will move.



The potential difference is measured in volts, and potential is commonly referred to as voltage. "I" is the symbol for current and "R" is the symbol for the resistance of the system. Current is measured in amperes and resistance is measured in ohms.

Ohm’s Law

This section will describe what electricity is, how it is generated, and how it behaves. Voltage, current, resistance and power are explained in this lesson, and Ohm’s Law is used to explain their relationship in an electric circuit.

Ohm's Law explains the relationship between voltage current and resistance in a circuit. If we know the value of any two, we can calculate the third.

OHM'S LAW: E = I x R

In the formula:

E is the Electromotive Force or the potential difference, in volts, which is moving current through the conductor.

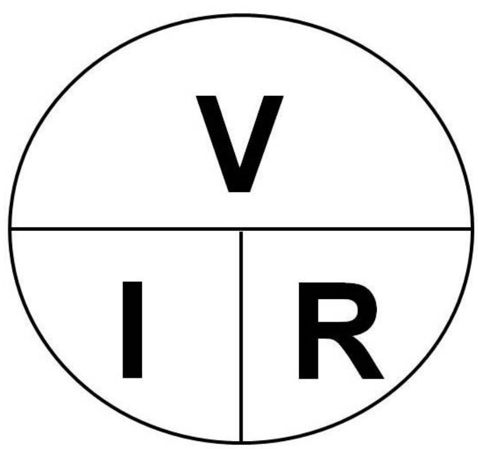
I is the intensity of electron flow, or Current, in Amperes, moving through the conductor.

R is Resistance, in Ohms, or opposition to the electron flow in the conductor.

Ohm's Law tells us that:

a) Current is inversely proportional to resistance. If resistance increases, current decreases; if resistance decreases, current increases.

b) Current is directly proportional to Voltage. That is, if voltage goes up, so does current; if voltage goes down, and so does current.

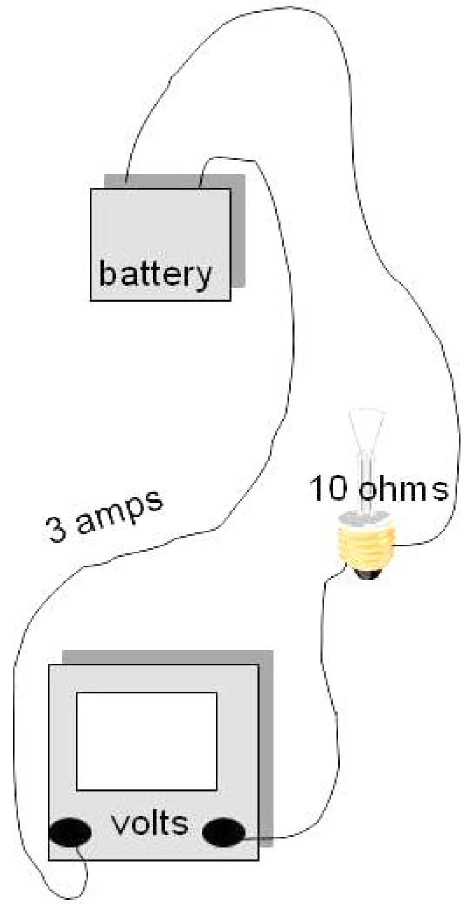


Now solve the following problems using Ohm's Law.

1. How much current will the load draw?

2. What is the resistance of the load?

3. What is the source voltage?



Common Symbols:
E =VOLTS ~or~ (V = VOLTS)
P =WATTS ~or~ (W = WATTS)
R = OHMS ~or~ (R = RESISTANCE)
I =AMPERES ~or~ (A = AMPERES)
HP = HORSEPOWER
PF = POWER FACTOR
kW = KILOWATTS
kWh = KILOWATT HOUR
VA = VOLT-AMPERES
kVA = KILOVOLT-AMPERES
C = CAPACITANCE
EFF = EFFICIENCY (expressed as a decimal)

DIRECT CURRENT FORMULAS

AMPS=	WATTS÷VOLTS	I = P ÷ E	A = W ÷ V
WATTS=	VOLTS x AMPS	P = E x I	W = V x A
VOLTS=	WATTS ÷ AMPS	E = P ÷ I	V = W ÷ A
HORSEPOWER=	(V x A x EFF)÷746		
EFFICIENCY=	(746 x HP)÷(V x A)		

AC SINGLE PHASE FORMULAS

AMPS=	WATTS÷(VOLTS x PF)	I=P÷(E x PF)	A=W÷(V x PF)
WATTS=	VOLTS x AMPS x PF	P=E x I x PF	W=V x A x PF
VOLTS=	WATTS÷AMPS	E=P÷I	V=W÷A
VOLT-AMPS=	VOLTS x AMPS	VA=E x I	VA=V x A
HORSEPOWER=	(V x A x EFF x PF)÷746		
POWERFACTOR=	INPUT WATTS÷(V x A)		
EFFICIENCY=	(746 x HP)÷(V x A x PF)		

AC THREE PHASE FORMULAS

AMPS=	WATTS÷(1.732 x VOLTS x PF)	I = P÷(1.732 x E x PF)
WATTS=	1.732 x VOLTS x AMPS x PF	P = 1.732 x E x I x PF
VOLTS=	WATTS÷AMPS	E=P÷I
VOLT-AMPS=	1.732 x VOLTS x AMPS	VA=1.732 x E x I
HORSEPOWER=	(1.732 x V x A x EFF x PF)÷746	
POWERFACTOR=	INPUT WATTS÷(1.732 x V x A)	
EFFICIENCY=	(746 x HP)÷(1.732 x V x A x PF)	

What is Electrical Resistance?

The **electrical resistance** of an electrical conductor is the opposition to the passage of an electric current through that conductor; the inverse quantity is **electrical conductance**, the ease at which an electric current passes.

Electrical resistance shares some conceptual parallels with the mechanical notion of friction.

The SI unit of electrical resistance is the ohm (Ω), while electrical conductance is measured in Siemens (S).

An object of uniform cross section has a resistance proportional to its resistivity and length and inversely proportional to its cross-sectional area. All materials show some resistance, except for superconductors, which have a resistance of zero.

The resistance (R) of an object is defined as the ratio of voltage across it (*V*) to current through it (*I*), while the conductance (G) is the inverse:

$$R = \frac{V}{I}, \qquad G = \frac{I}{V}, \qquad G = \frac{1}{R}$$

For a wide variety of materials and conditions, *V* and *I* are directly proportional to each other, and therefore *R* and *G* are constant (although they can depend on other factors like temperature or strain). This proportionality is called Ohm's law, and materials that satisfy it are called "Ohmic materials."

In other cases, such as a diode or battery, *V* and *I* are *not* directly proportional, or in other words the *I*–*V* curve is not a straight line through the origin, and Ohm's law does not hold.

In this case, resistance and conductance are less useful concepts, and more difficult to define.

The ratio V/I is sometimes still useful, and is referred to as a "chordal resistance" or "static resistance", as it corresponds to the inverse slope of a chord between the origin and an *I*–*V* curve.

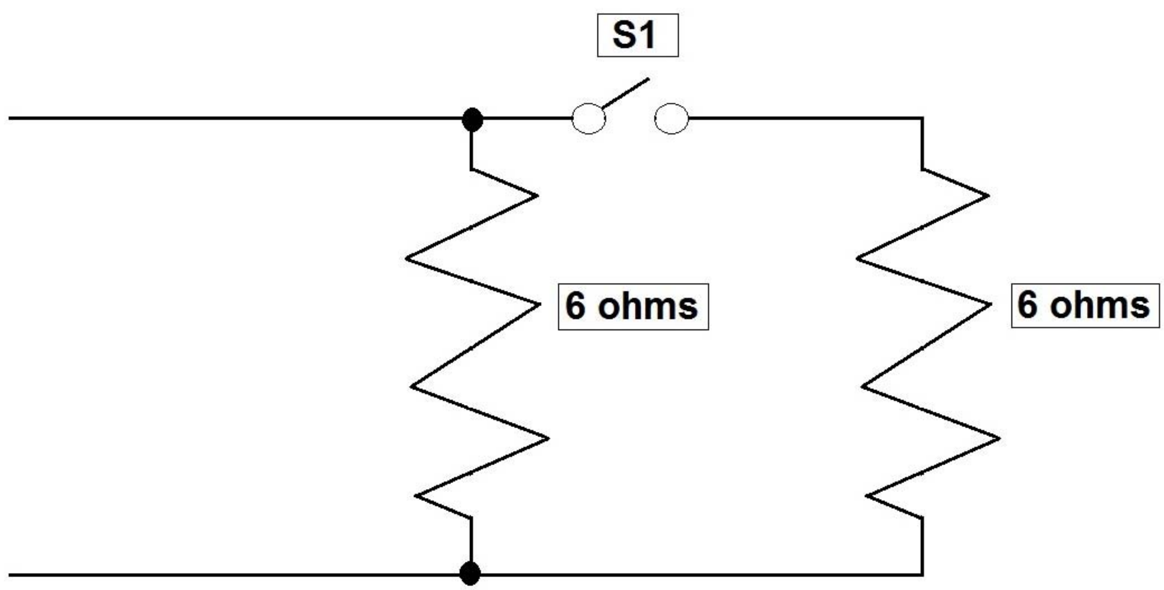
In other situations, the derivative $\frac{dV}{dI}$ may be most useful; this is called the "differential resistance".

Ohm's Idea

A reliable tangent galvanometer can easily be constructed by looping a wire around a platform that supports a compass.

Different lengths of resistance wire are connected to the tangent galvanometer in a manner similar to Ohm's actual experiments. For convenience, a nichrome resistance wire can be laid across a meter stick, and using a sliding contact, different lengths of wire can easily be obtained.

The magnetic field of the loop is aligned in a North-South direction and the tangents of the deflections of the compass needle (current) are graphed versus the resistance (measured by length) to confirm that the current is inversely proportional to the resistance of the circuit.



What resistance would you expect to measure across the open switch S1?

Ohm’s Experiment

1. Set up the apparatus as shown. Leave one connection at the battery open (or use a switch to turn the current on and off).

2. Prepare several lengths of resistance wire or use a sliding connection to a resistance wire 1 meter long.

3. Beginning with the longest wire first, connect the circuit and measure the deflection of the compass. Be sure your compass needle moves freely (you may lightly tap the platform to check). Note: disconnect the battery as soon as you record the deflection of the compass needle. Leaving the battery connected could heat the wires and change the resistance.

Data Table

Resistance Length (m)	0.20	0.40	0.60	0.80	1.00
θ (degrees)					
Tan θ					

4. Graph Current (tan2) versus Resistance (length of wire).
5. “Straighten” the curve to determine the relationship between current and resistance.
6. What does the constant represent?
7. Repeat the experiment using an ammeter instead of a tangent galvanometer.

Conclusion
We have demonstrated that

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

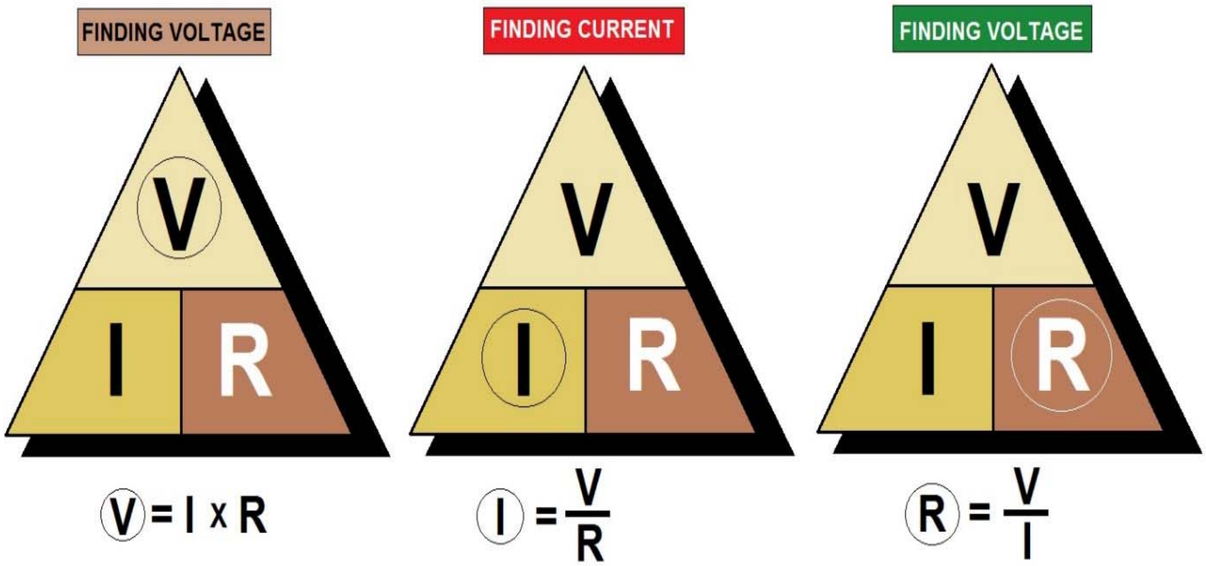
where *I* is current, *R* is the total resistance, and *a* is a constant. *RT* = *b* + *x*, where *x* is the resistance wire and *b* is the fixed resistance of the circuit.

Can you calculate *b* in terms of length? Proportion of total resistance?

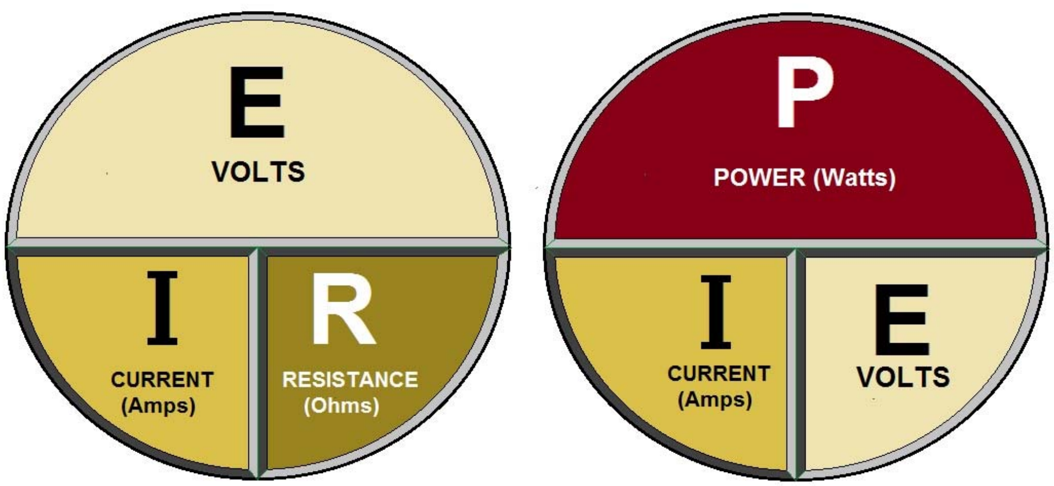
Ohm repeated the experiment with a different temperature difference and found a different value for *a*. The constant *a* must be associated with the battery, but what it meant was left for Kirchoff to determine 25 years later. Kirchoff synthesized Coulomb's law, electric potential energy between two charges, Joule's experiment, and Ohm's experiments into a coherent mathematical theory.

GEORG OHM

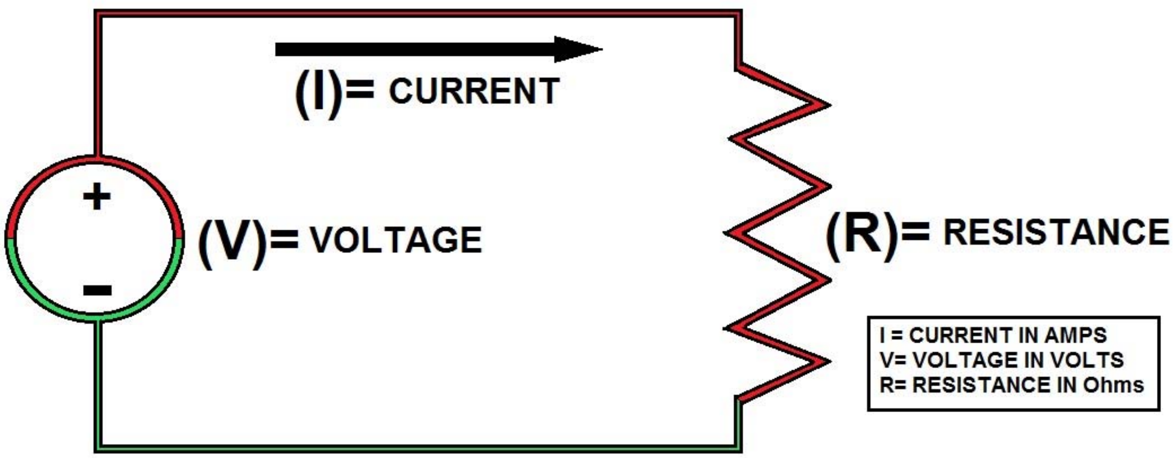
Georg Ohm measuring the current passing through the copper strip. The current is generated by the bismuth copper thermocouple. One metal junction is dipping in ice and the other in boiling water. Because there is a constant temperature difference the EMF does not vary.



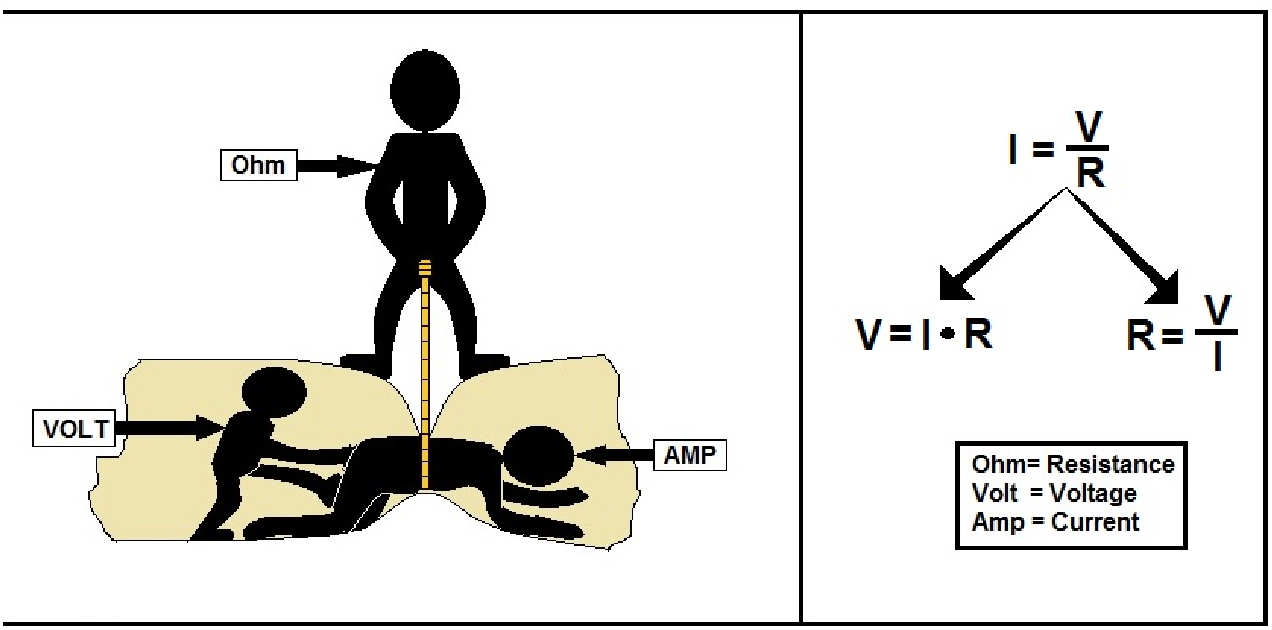
OHM'S LAW FORMULAS



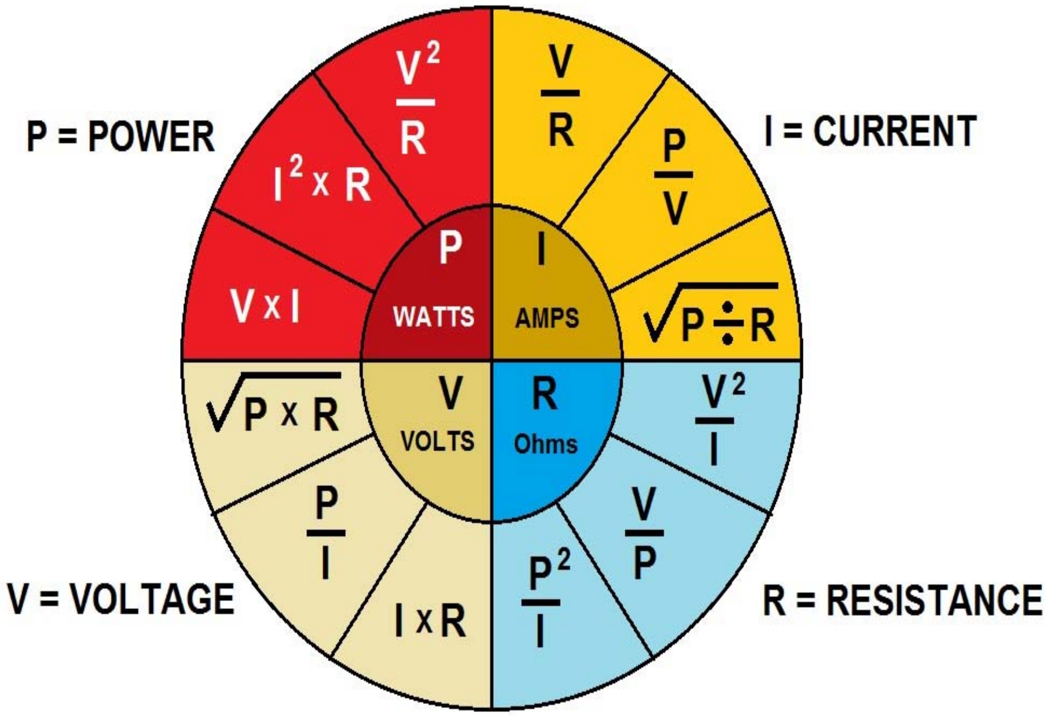
OHM'S LAW



Ohm's LAW



BASIC EXAMPLE OF Ohm's LAW

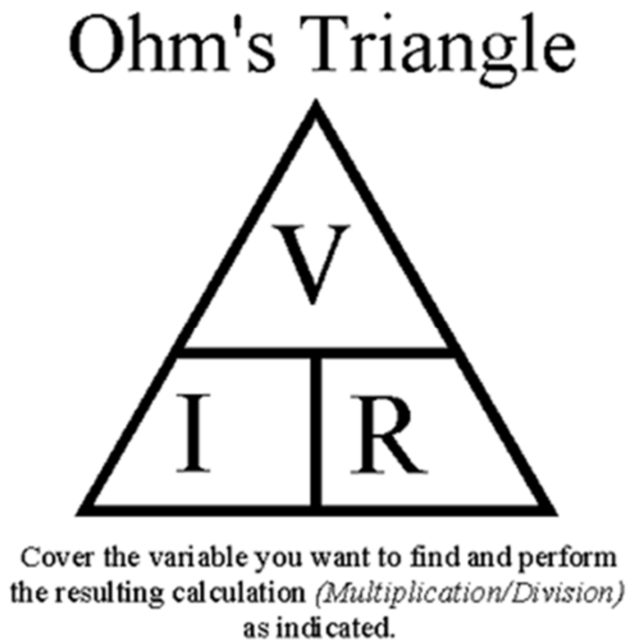


Technical Learning College

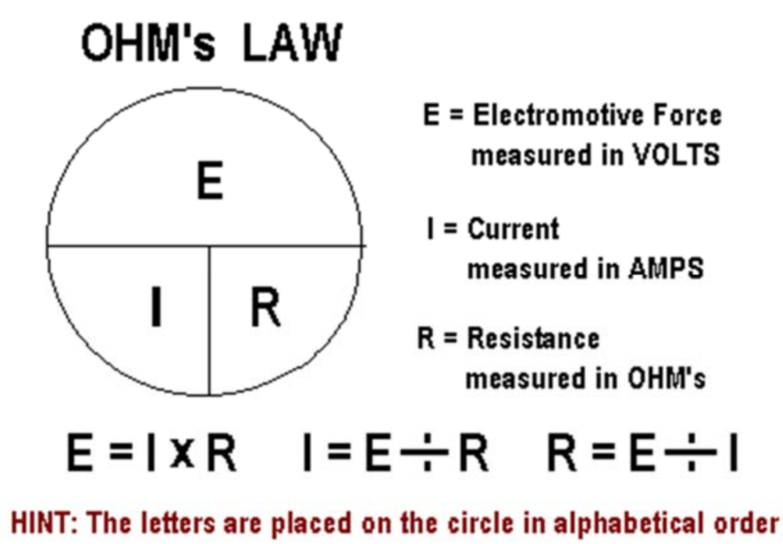
Ohm's LAW CALCULATOR

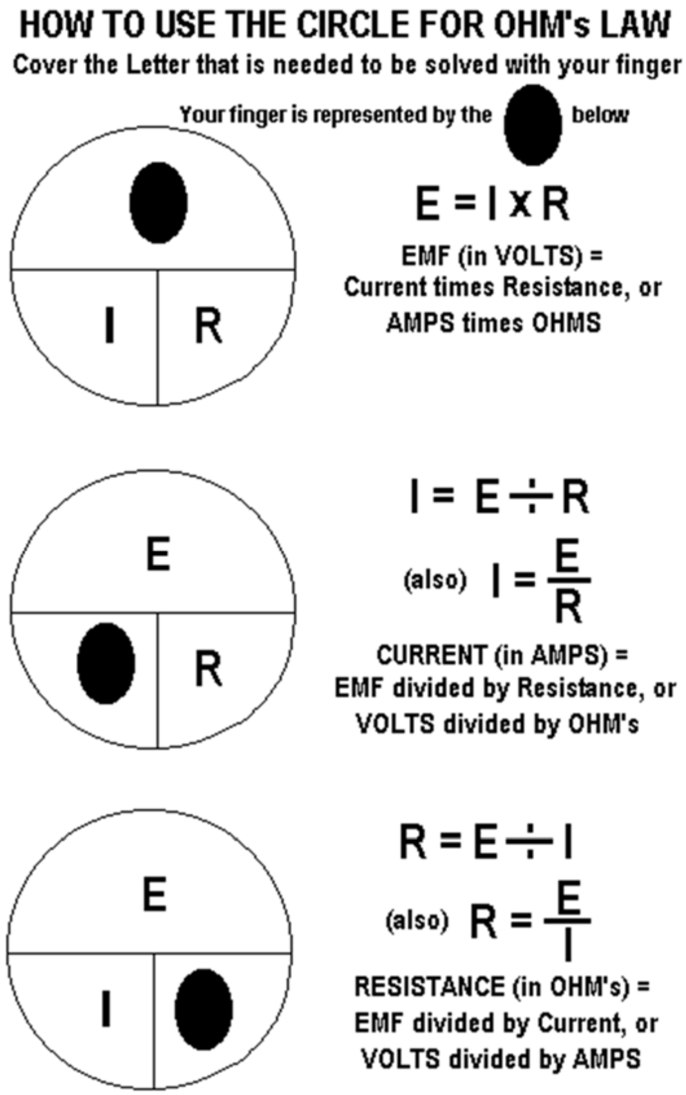
Kirchoff's Contribution

By experimentation Ohm found that in an electric circuit...



Or also expressed as





V comes from "voltage" and ***E*** from "electromotive force". ***E*** means also **energy**, so ***V*** is chosen.

Energy = voltage × charge. $E = V \times Q$. Some like better to stick to ***E*** instead to ***V***, so do it.

Voltage $V = I \times R = P / I = \sqrt{P \times R}$ in volts V

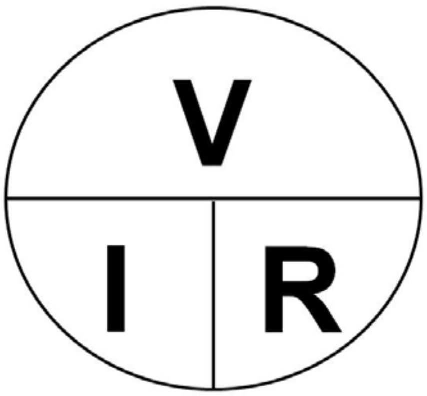
Current $I = V / R = P / V = \sqrt{P / R}$ in amperes A

Resistance $R = V / I = P / I^2 = V^2 / P$ in ohms Ω

Power $P = V \times I = R \times I^2 = V^2 / R$ in watts W

Memory wheels provide an easy way to remember the relationship in Ohm’s Law. If you cover the V (E is sometimes used for EMF, electrical motive force), the wheel tells you that “V” (voltage) is equal to “I” (current or amperage) multiplied by “R” (resistance).

By covering I or R you would divide by V, for example:



I = V ÷ R

R = V ÷ I

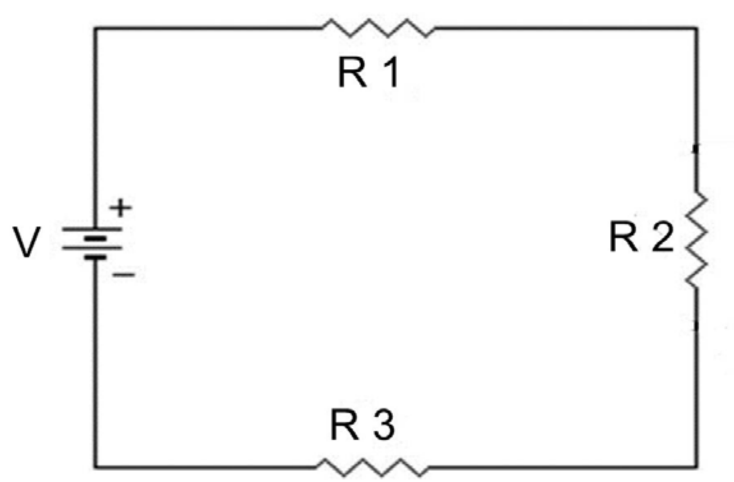
V = I x R

Now solve the following problems using Ohm’s Law. Some of the answers will have decimal points.

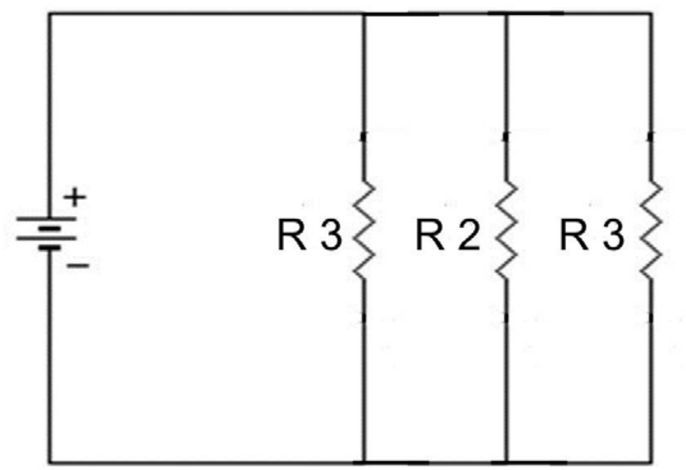
Series and Parallel Circuit Formulas

Series Resistance	
Method for ALL Resistors in Series	Rt = R1 + R2 + R3 . . .
Current total	$I_t = I_1 = I_2 = I_3$
Voltage total	Vt = V1 + V2 + V3
Power total	Pt = P1 + P2 + P3
Parallel Resistance	
Method for ONLY 2 resistors	Rt = (R1 x R2) / (R1 + R2)
Method for multiple resistors	$Rt\ or\ R\ eq = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \cdots}$
Current total	$I_t = I_1 + I_2 + I_3$
Voltage total	Vt = E1 = E2 = E3
Power total	Pt = P1 + P2 + P3

Series Circuit

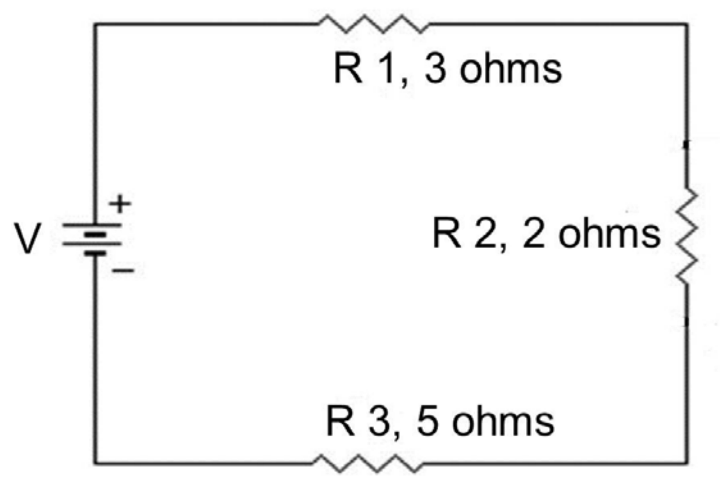


Parallel Circuit



Examples how to solve series circuits using the formula:

Rt = R1 + R2 + R3 . . .



Rt = 3 R + 2 R + 5 R
Rt = 10 R

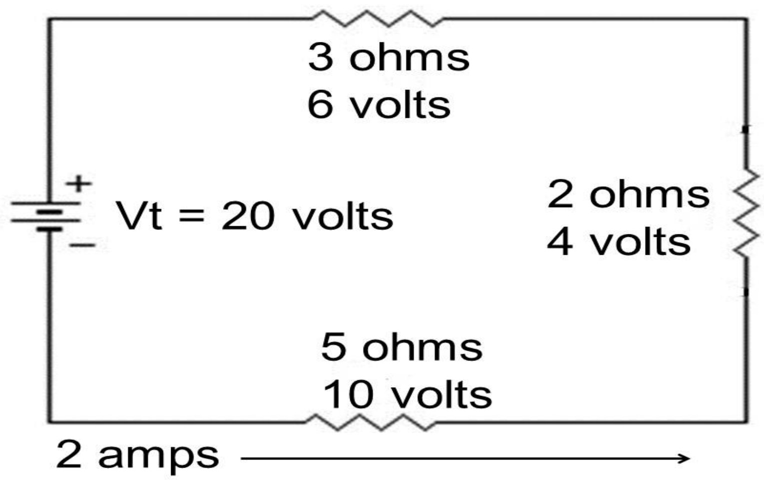
As you can see it's an easy process just follow the formula. For our next example we will drop the numbering of the "R" and just indicate the value.

Let's look at how voltage and amperage works in a series circuit:

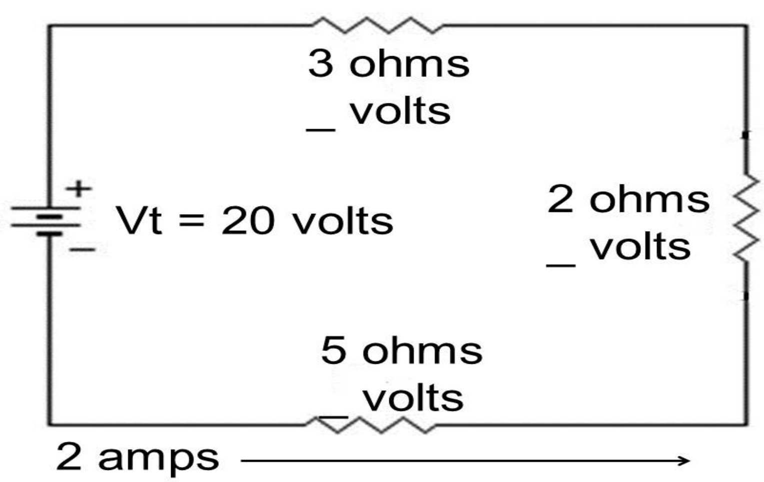
Vt = V1 + V2 + V3

$I_t = I_1 = I_2 = I_3$

This is how the circuit would look:



If amps remain the same throughout the circuit then you would have a voltage drop across each load of resistance. This is done by using Ohm's Law. Let's take a close look and see what happens when we take the voltage drops out.



5 R x 2 I = 10 V, 2 R x 2 I = 4 V, and 3 R x 2 I = 6 V add all the volts and you get 20. Whenever solving any type of circuit have your formulas written down somewhere handy.

The series circuit formulas we used where:

V= I x R

Vt = V1 + V2 + V3

$I_t = I_1 = I_2 = I_3$
Rt = R1 + R2 + R3

In a parallel circuit we use the following formulas for voltage and amperage:

Vt = E1 = E2 = E3
$I_t = I_1 + I_2 + I_3$

Resistance is a little more complicated:

$$Rt\ or\ R\ eq = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \cdots}$$

The "eq" is equivalent, in this formula 1 is divided by fractions and each fraction is added together. Remember simplify all the numbers before dividing what's on top from the bottom. Have I lost you yet? Let's give it a try with numbers:

$$Rt = \frac{1}{\frac{1}{R\ 20} + \frac{1}{R\ 30} + \frac{1}{R\ 40} + \cdots}$$

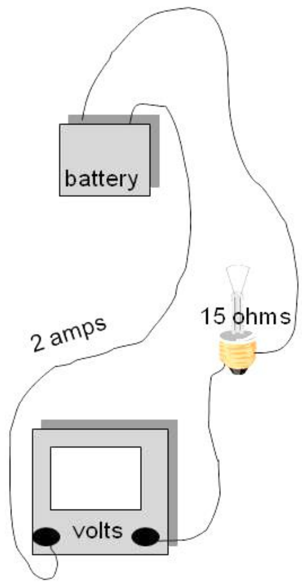
$\frac{1}{20}$ =.05 $\frac{1}{30}$ =.0333 $\frac{1}{40}$ =.025

.05 + .0333 + .025 = .1083

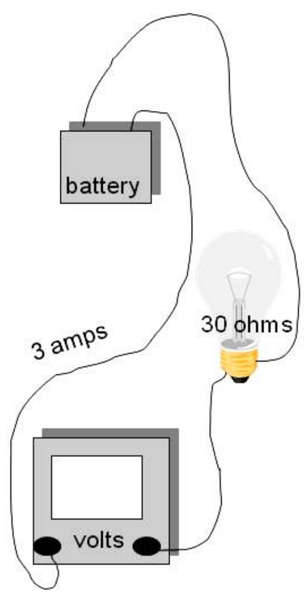
$$Rt\ 9.23 = \frac{1}{.1083}$$

When current is traveling through a load or resistor it goes in and comes out.

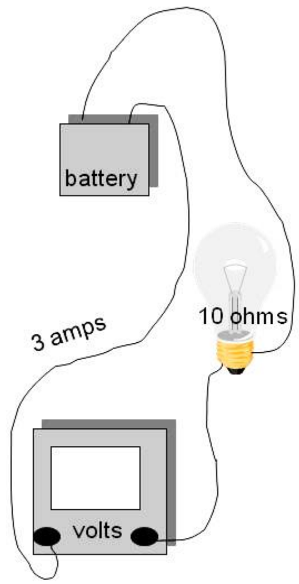
Section 5 – Electrical Laws and Theories Post Quiz



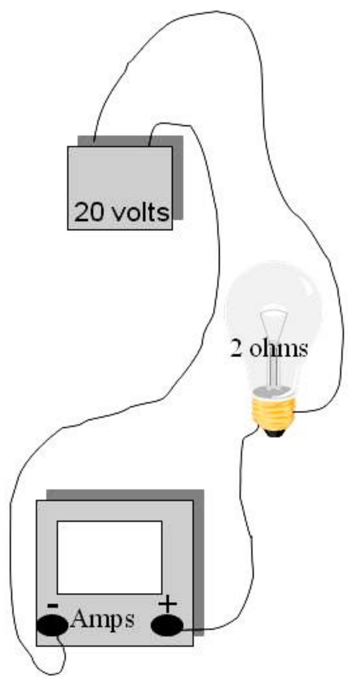
1. What is the voltage for the above? ____



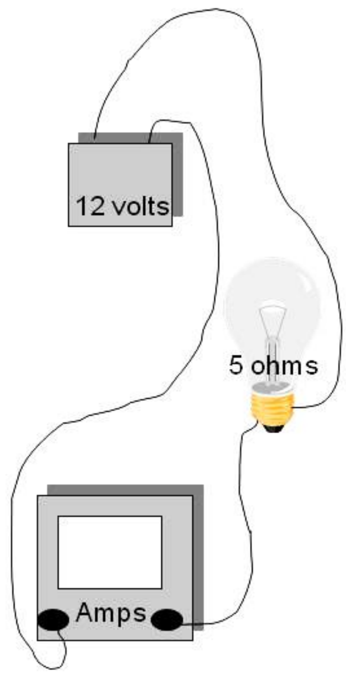
2. What is the voltage for the above? ____



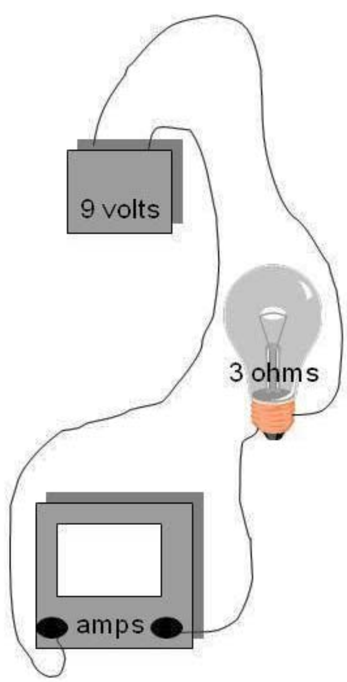
3. What is the voltage for the above? ____



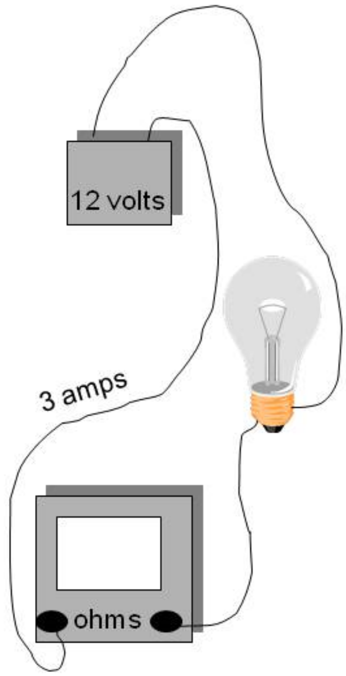
4. How much current will the load draw? ____



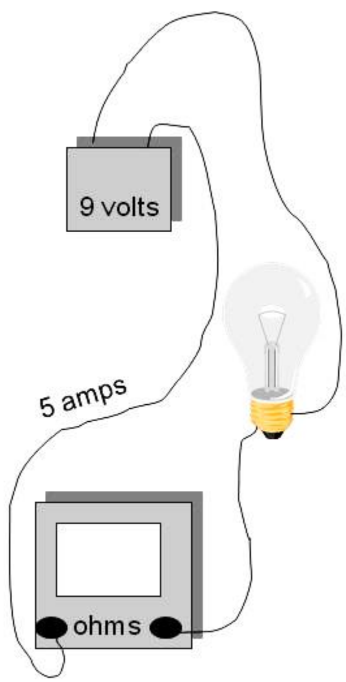
5. How much current will the load draw? ____



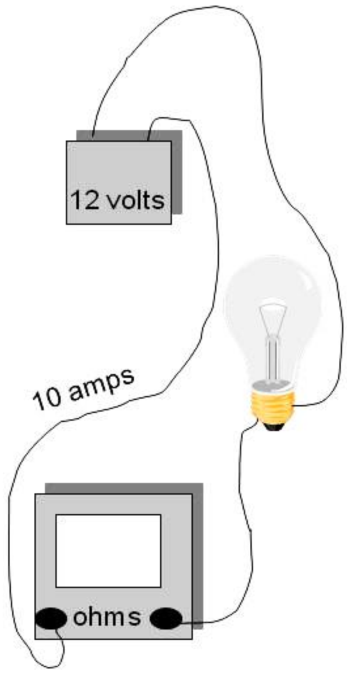
6. How much current will the load draw? ____



7. What is the resistance of this load? ____



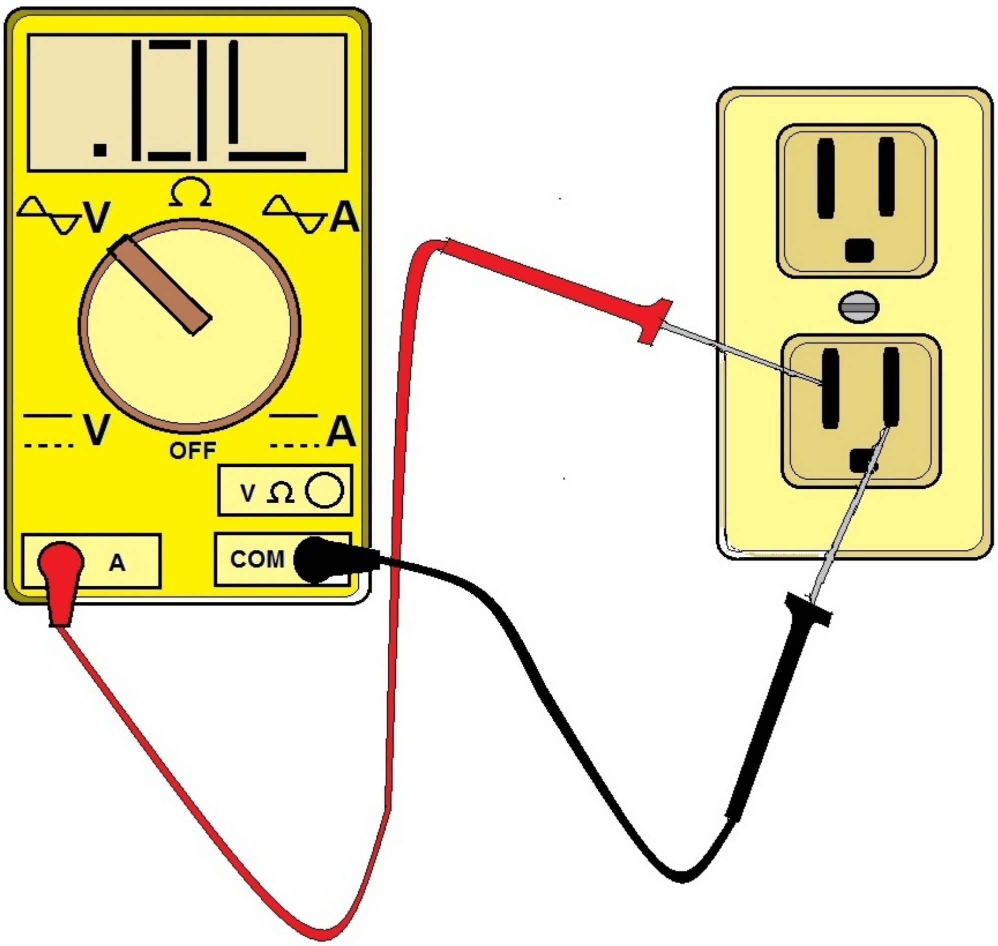
8. What is the resistance of this load? ____



9. What is the resistance of this load? ____

Answers for Practice Exercise 1-9

1. 2 I X 15 R = 30 V
2. 3 I x 30 R = 90 V
3. 3 I x 10 R = 30 V
4. 20 V ÷ 2 R = 10 I (amps)
5. 12 V ÷ 5 R = 2.4 I (amps)
6. 9 V ÷ 3 R = 3 I (amps)
7. 12 V ÷ 3 I = 4 R
8. 9 V ÷ 5 I = 1.8 R
9. 12 V ÷ 10 I = 1.2 R



SHORT CIRCUIT

Section 6 – Classical Mechanics- Potential and Potential Difference

Section Focus: You will learn advanced electrical theories and laws. At the end of this section, you will be able to understand and describe simple forms of voltage drop theories. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: In order to understand electrical principles, we first need to explain the various simple forms of electrical potential and voltage drop in scientific laws and theories. Because this area of study is quite large and detailed, we will only focus upon simple electrical classical electrical mechanics. laws and theories.

$$V = \frac{W}{Q} \quad or \quad V = \frac{E}{Q}$$

V = Potential Difference (Voltage)
W = Work done
E = Energy
Q = Charge

Classical Mechanics

Objects may possess a property known as an electric charge. An electric field exerts a force on charged objects. If the charged object has a positive charge, the force will be in the direction of the electric field vector at that point. The force will be in the opposite direction if the charge is negative. The magnitude of the force is given by the quantity of the charge multiplied by the magnitude of the electric field vector.

A net force acting on an object will cause it to accelerate, as explained by Classical mechanics which explores concepts such as force, energy, potential etc. The electric potential (or simply potential) at a point in an electric field is defined as the work done in moving a unit positive charge from infinity to that point. The electric potential at infinity is assumed to be zero.

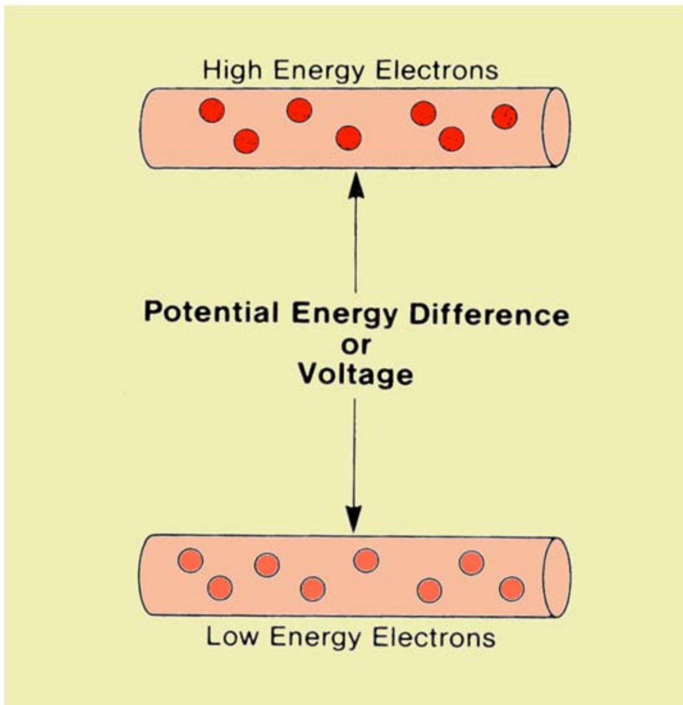
Force and potential energy are directly related. As an object moves in the direction that the force accelerates it, its potential energy decreases. For example, the gravitational potential energy of a cannonball at the top of a hill is greater than at the base of the hill. As the object falls, that potential energy decreases and is translated to motion, or inertial (kinetic) energy.

For certain force fields, it is possible to define the "potential" of a field such that the potential energy of an object due to a field depends only on the position of the object with respect to the field. Those forces must affect objects depending only on the intrinsic properties of the object (e.g., mass or charge) and the position of the object, and obey certain other mathematical rules.

Later, Joule demonstrated that $P = I^2R$. Both experiments are examples of scientific laws developed inductively from observations of the behavior of electric circuits. Additionally, both experiments are concerned with charges in motion. Kirchoff started with the energy considerations of static charges and showed the following.

Electric Potential

Electric potential is the electric potential energy ***per unit charge***.



Thus, Kirchoff demonstrated that if the constant in Ohm's Law was voltage, that everything we knew about in terms of static and dynamic electricity fit together in a coherent theoretical and practical system (in other words, it is a good theory).

This portion of the unit contains many easy places to develop misunderstandings.

They have all been addressed earlier on this page but here is a quick list of them.

Please go out of your way to keep these from becoming a misunderstanding for you:

- Electric Potential Energy is **not** the same as Electrical Potential.
    - Electrical Potential can also be described by the terms, potential difference, voltage, potential drop, potential rise, electromotive force, and EMF. These terms may differ slightly in meaning depending on the situation.
- The variable we use for potential difference is V and the unit for potential difference is also V (volts). Don't let that confuse you when you see V = 1.5V
- The electron volt is not a smaller unit of the volt, it's a smaller unit of the Joule.

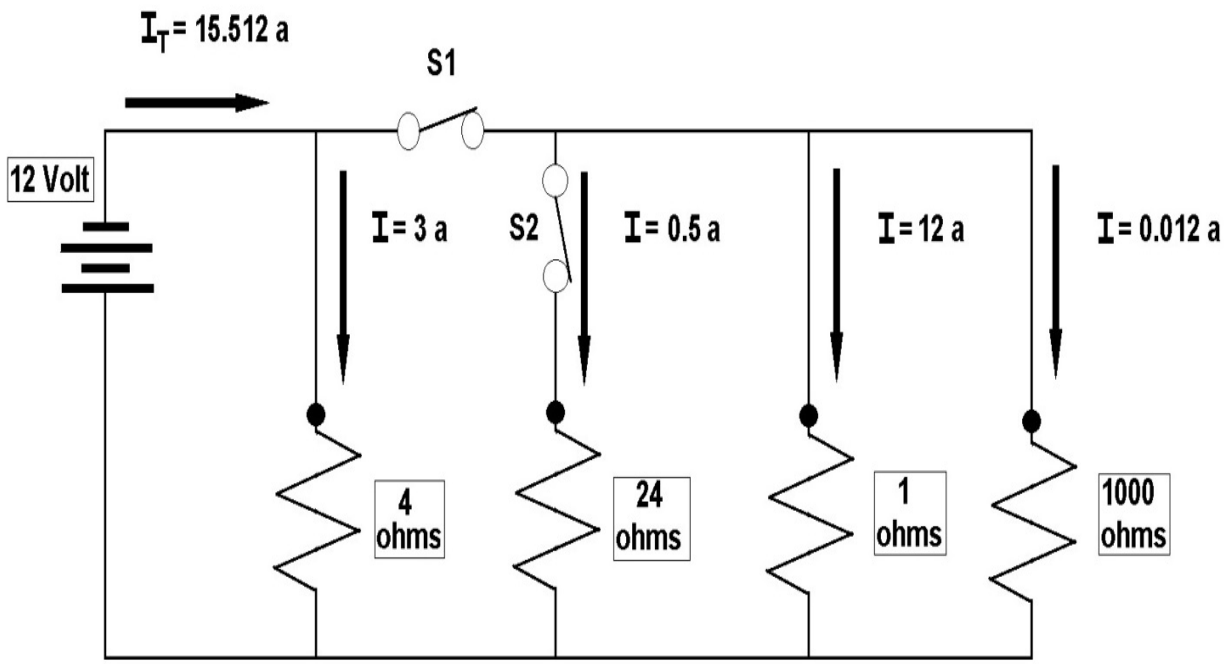
Determine the resistance, current, voltage, and power for series, parallel, and combined networks.

KIRCHOFF'S LAW

The net current at any point in a circuit is zero.
OR
What flows in flows out again.
OR
Current flows in circles.
THEREFORE
All signals are differential.
AND
Ground impedance matters.

Circuit analysis would begin with simple series and simple parallel circuits. The following is an example of the analysis of a combined network or complex circuit.

In the circuit below, determine the current, the voltage drop, and the power consumed by each resistor.



Potential Difference

The voltage difference between any two points in a circuit is known as the **Potential Difference**, **pd** or **Voltage Drop** and it is the difference between these two points that makes the current flow. Unlike current which flows around a circuit in the form of electrical charge, potential difference does not move it is applied.

The unit of potential difference is the **volt** and is defined as the potential difference across a resistance of one ohm carrying a current of one ampere. In other words, V = I.R

Ohm's Law states that for a linear circuit the current flowing through it is proportional to the potential difference across it so the greater the potential difference across any two points the bigger will be the current flowing through it.

For example, if the voltage at one side of a 10Ω resistor measures 8V and at the other side of the resistor it measures 5V, then the potential difference across the resistor would be 3V (8 - 5) causing a current of 0.3A to flow.

If however, the voltage on one side was increased from 8V to say 40V, the potential difference across the resistor would now be 40V - 5V = 35V causing a current of 3.5A to flow. Note that the voltage at any point in a circuit is always measured with respect to a common point, generally 0V.

For electrical circuits, the earth or ground potential is usually taken to be at zero volts (0V) and everything is referenced to that common point in a circuit. This is similar in theory to measuring height. We measure the height of hills in a similar way by saying that the sea level is at zero feet and then compare other points of the hill or mountain to that level.

In a very similar way we can call the common point in a circuit zero volts and give it the name of ground, zero volts or earth, then all other voltage points in the circuit are compared or referenced to that ground point.

As the units of measure for **Potential Difference** are volts, potential difference is mainly called **voltage**. Individual voltages connected in series can be added together to give us a "total voltage" sum of the circuit as seen in the resistors in series tutorial. Voltages across components that are connected in parallel will always be of the same value as seen in the resistors in parallel tutorial, for example.

for series connected voltages,

$$V_T = V_1 + V_2 + V_3 \text{ ... etc}$$

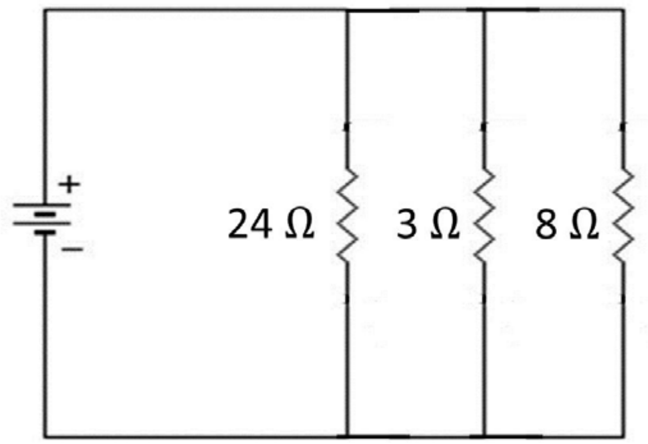
for parallel connected voltages,

$$V_T = V_1 = V_2 = V_3 \text{ ... etc}$$

The circuit is neither a simple series nor a simple parallel connection of resistors. It contains both groupings, so it is an example of a complex circuit.

Generally, it is necessary to determine the total or equivalent resistance of the circuit before other electrical quantities can be calculated. In such a complex circuit, it is necessary to identify the resistors that are in series with each other and those that are in parallel with each other. These groups of resistors can be added together to reduce the number of resistors in the circuit. This process continues until the circuit is reduced to a single resistor.

Usually, begin by looking at resistors furthest from the source. In this case, the 2 Ω and 6 Ω resistor are in series and may be combined to a single value of 8 Ω. At the same time, 20 Ω and 4 Ω may be combined to give 24 Ω.



$$Rt\ or\ R\ eq = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \cdots}$$

$$Rt = \frac{1}{\frac{1}{24\ \Omega} + \frac{1}{3\ \Omega} + \frac{1}{8\ \Omega}}$$

$$Rt = \frac{1}{.0416 + .3333 + .125}$$

$$Rt = \frac{1}{.4999}$$

$$Rt = 2\ \Omega$$

The circuit now consists of three resistors in series. The total resistance for the entire circuit is $R_T = 1 + 2 + 7 = 10\ \Omega$.

This is often called the equivalent resistance, and this simple circuit, consisting of a single source and a single resistor, is known as the equivalent circuit.

The equivalent resistance of 10 Ω draws the same amount of current from the power supply as the original complex network.

To complete the analysis, we work backwards to the original circuit, applying Kirchoff's laws:

• Kirchoff's Current Law: The sum of currents entering a junction must equal the sum of currents leaving that junction.

• Kirchoff's Voltage Law: The sum of potential drops around a circuit must equal the sum of potential rises around the circuit.

Once the total resistance is calculated, find the total current that leaves and returns to the

$$\text{Source } I = \frac{V}{R} = \frac{30\text{ V}}{10\ \Omega}$$

This is called the main line of the circuit since it has the total current in it. It is helpful to draw this in the circuit.

This total current passes through the 1 Ω and 7 Ω resistors. This results in a voltage drop across each of them.

$$V_{\text{drop}} = IR = (3\ A)\ (1\ \Omega) = 3\ V \text{ and}$$

$$V_{\text{drop}} = (3\ A)(7\ \Omega) = 21\ V$$

The voltage drop left for the remainder of the circuit is 30 V – 24 V = 6 V.
This 6 V appears across the three parallel branches so the current in each branch can be determined. Since voltages across parallel resistances are the same:

$$I = \frac{V}{R} = \frac{6\text{ V}}{24\ \Omega} = 0.25\ A$$

$$I = \frac{V}{R} = \frac{6\text{ V}}{3\ \Omega} = 2\ A$$

$$I = \frac{V}{R} = \frac{6\text{ V}}{8\ \Omega} = 0.75\ A$$

The voltage drop across the 20 Ω and 4 Ω resistors may be calculated.

$$V_{drop} = IR = (0.25\ A)(20\ \Omega) = 5\ V \text{ across the 20 } \Omega \text{ resistor}$$

The voltage drop across the 4 Ω resistor can be found the same way or by using Kirchoff's

Voltage Law
Since 6 *V* appears across both resistors and the 20 Ω resistor has a drop of 5 *V* across it, then the 4 Ω resistor has a drop of 6 *V* – 5 *V* = 1 *V*.

A similar method can be used to find the voltage drops across the 2 Ω and 6 Ω resistors. For the 2 Ω resistor: *V*drop = *IR* = (0.75 *A*)(2 Ω) = 1.5 *V*. The voltage drop across the 6 Ω resistor is 6 *V* – 1.5 *V* = 4.5 *V*.

Use Watt's Law or its two variations to find the power consumed by each resistor:

For the 1 Ω and 7 Ω series resistors in the main line of the circuit:

$$P = IV = (3\ A)(1\ \Omega) = 3\ W$$

$$P = IV = (3\ A)(7\ \Omega) = 21\ W$$

For the 20 Ω and 4 Ω resistors that are in series with each other, but part of the parallel group:

$$P = I^2R = (0.25\ A)^2(20\ \Omega) = 1.25\ W$$

$$P = I^2R = (0.25\ A)^2\ (4\ \Omega) = 0.25\ W$$

The 3 Ω resistor has a voltage drop of 6 *V* across it.

$$P = I^2R = (0.75\ A)^2(2\ \Omega) = 1.125\ W$$

$$P = I^2R = (0.75\ A)^2\ (6\ \Omega) = 3.375\ W$$

The 2 Ω and 6 Ω resistors are in series and have the same current through them.

$$P = I^2R = (0.75\ A)^2(2\ \Omega) = 1.125\ W$$

$$P = I^2R = (0.75\ A)^2\ (6\ \Omega) = 3.375\ W$$

Note that these values may be obtained in different ways by using different variations of Watt's Law, Ohm's Law, or Kirchoff's Laws. This provides the students with excellent problem-solving practice.

Also note that conventions regarding significant figures have not been adhered to in this example. This allows one to verify results obtained by different methods of calculation.

Ohms Law				
METHOD	**Resistance**	**Current**	**Voltage**	**Power**
1	**V / I**	**V / R**	**R x I**	**V x I**
2	**P / I^2**	**P / V**	**P / I**	**I^2 x R**
3	**V^2 / P**	**(P / R)^.5**	**(P x R)^.5**	**V^2 / R**

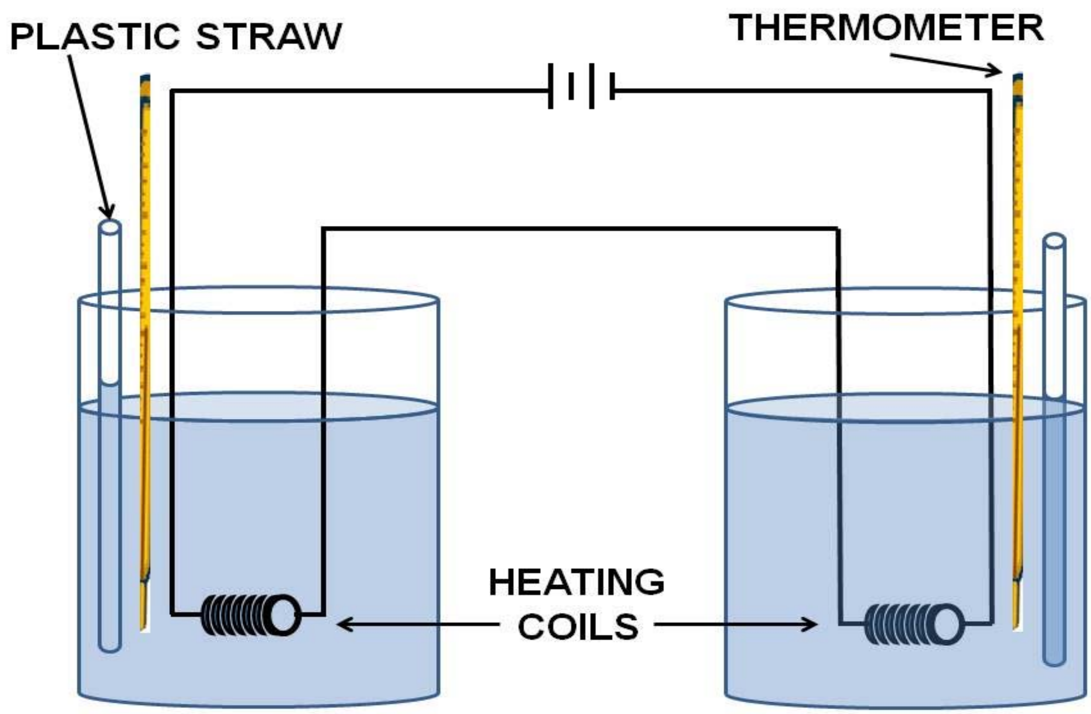
Parallel Resistance	
Method for ONLY 2 resistors	**Rt = (R1 x R2) / (R1 + R2)**
Method for multiple resistors	
Current total	**$I_t = I_1 + I_2 + I_3$ I**
Voltage total	**Vt = E1 = E2 = E3**
Power total	**Pt = P1 + P2 + P3**

Series Resistance	
Method for ALL Resistors in Series	Rt = R1 + R2 + R3 . . . Rn
Current total	$I_t = I_1 = I_2 = I_3$
Voltage total	Vt = V1 + V2 + V3
Power total	Pt = P1 + P2 + P3

Series Capacitance	
Method for ONLY 2 capacitors	Ct = (C1 x C2) / (C1 + C2)
Method for multiple capacitors	1 / Ct = [(1 / C1) + (1 / C2) + . . . (1 / Cn)]

Parallel Capacitance	
Method for ALL Capacitors in Series	Ct = C1 + C2 + C3 . . . Cn

Power, Resistance, and Current



JOULE EXPERIMENT

Introduction

James Prescott Joule first explored the relationships among power, resistance, and electric current in 1841. We shall attempt to duplicate his efforts with this experiment.

As current passes through a coil of wire, it generates heat. The heat is transferred to water in a simple calorimeter (Styrofoam™ cup). You will calculate the heat gained by the water and the power of the heating coil. You may then determine the relationships graphically.

Part 1: Power and Resistance

Apparatus

- 6V or 12V battery
- nichrome heating coils
- Styrofoam™ cups and lids
- thermometers
- watch
- plastic straws
- 100 mL graduate
- patch cords
- ohmmeter

Procedure

1. Prior to the experiment, allow sufficient water to reach room temperature.
2. Pour exactly 100 mL of water into each Styrofoam™ cup. This will provide 100 g of water to be heated.
3. Measure the resistance of each coil. Record in the data table.
4. Assemble the battery and heating coils in series to provide an identical current through each coil. Leave one connection open until you are ready to begin the experiment.
5. Record the initial temperature, to the nearest 0.1° C, for each water sample. Record in the table.
6. Complete the circuit to allow current to pass through the coils. At one-minute intervals, gently stir the water samples with their straws. Observe the temperatures.
7. After sufficient heating has occurred, record the time elapsed and the final temperatures of each sample.
8. Calculate the heat developed from:

Heat = mass (g) x specific heat x temperature difference (°C)

$$H = mc\Delta T$$

Water has a specific heat of 4.2 J/g°C

Determine power:

Power = Energy (heat)/time
(Time must be measured in seconds.)

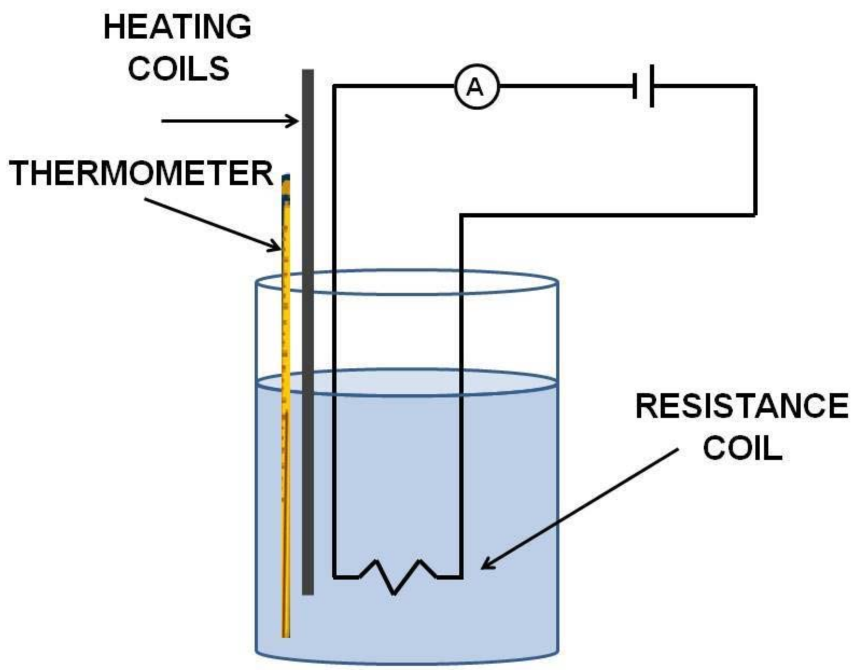
9. Plot a graph of power vs. resistance and graphically determine the relationship.

	Resistance	Resistance	Resistance	Resistance
Power				
Power				
Power				
Power				
Power				

Power and Current

Apparatus

- 6V battery
- heating coils of identical resistance
- resistance coil
- patch cords
- ammeter
- thermometer
- watch (or digital thermometer and LabPro)
- 100 mL graduated cylinder
- Styrofoam™ cups and lids



JOULE EXPERIMENT

Procedure

1. Prior to the experiment, allow about one liter of water to reach room temperature.
2. Pour exactly 100 mL of water into each Styrofoam™ cup. Place the heating coil and thermometer arrangement into the water and obtain an initial temperature reading to the nearest 0.1° C.
3. Prepare the circuit to deliver current to the heating coil and resistance coil in parallel. Be sure to connect the ammeter in series with the heating coil only.
4. Connect the D cell and begin recording time, current, and temperature readings every minute. Gently stir the water for a few seconds prior to reading the thermometer. Collect data until a temperature rise of at least a few degrees is noticed. Record in the data table.
5. Use a fresh sample of water and another heating coil. Adjust the resistance coil to a different value so a different current will pass through the heating coil. Repeat Step 4 above. Perform several different trials, using very different currents in identical heating coils.

6. Calculate the heat developed from:

Heat = mass (g) x specific x temperature heat difference (°C)
H = mcΔT

Water has a specific heat of 4.2 J/g °C

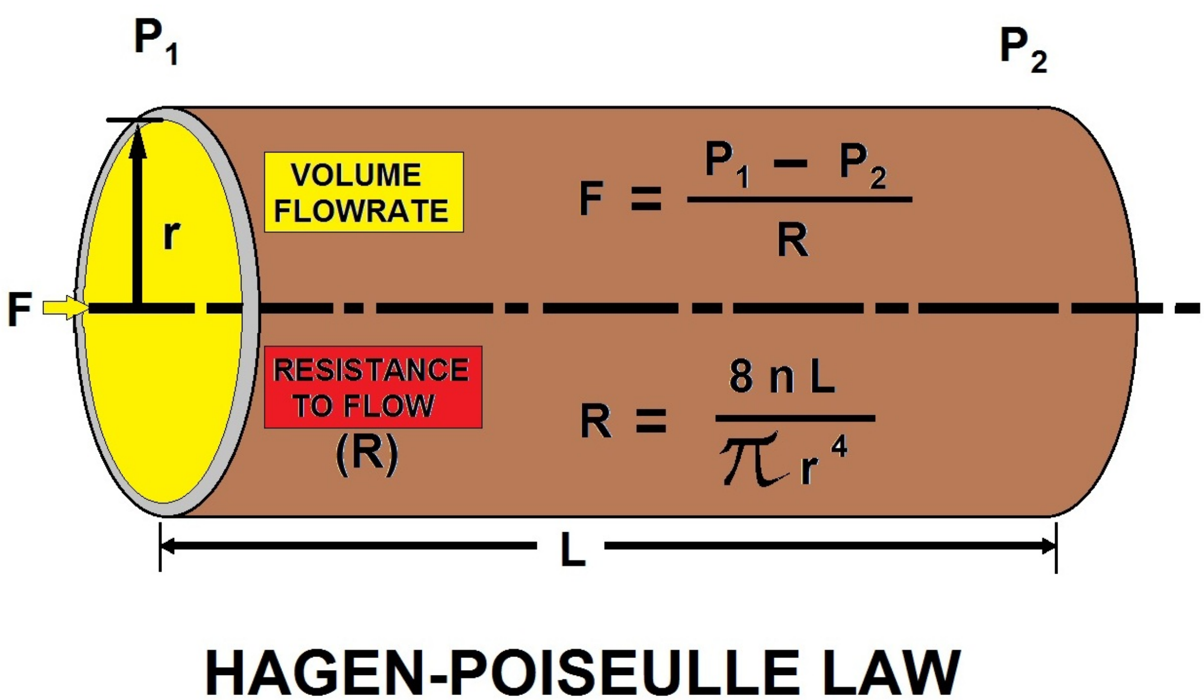
7. Determine power:

Power = Energy (heat)/time (Time must be measured in seconds.)

8. Plot a graph of power vs current. Perform graphical manipulations as required to determine the relationship between power and current.

Data Table: Power and Current

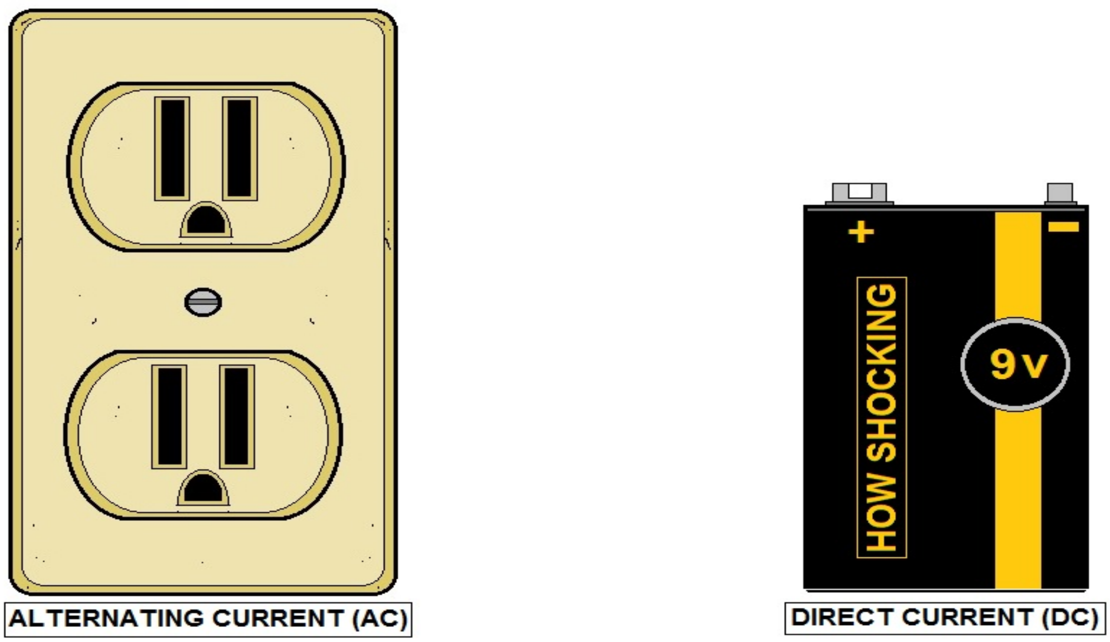
	Current	Current	Current	Current	Current	Current
Power						
Power						
Power						
Power						
Power						
Power						



Understanding Direct Current (DC) or Alternating Current (AC)

In engineering or household applications, current is often described as being either direct current (DC) or alternating current (AC). These terms refer to how the current varies in time. Direct current, as produced by example from a battery and required by most electronic devices, is a unidirectional flow from the positive part of a circuit to the negative. If, as is most common, this flow is carried by electrons, they will be travelling in the opposite direction. Alternating current is any current that reverses direction repeatedly; almost always this takes the form of a sine wave. Alternating current thus pulses back and forth within a conductor without the charge moving any net distance over time. The time-averaged value of an alternating current is zero, but it delivers energy in first one direction, and then the reverse.

Alternating current is affected by electrical properties that are not observed under steady state direct current, such as inductance and capacitance. These properties however can become important when circuitry is subjected to transients, such as when first energized.



ALTERNATING / DIRECT CURRENT EXAMPLES

Electric Field
The concept of the electric field was introduced by Michael Faraday. An electric field is created by a charged body in the space that surrounds it, and results in a force exerted on any other charges placed within the field. The electric field acts between two charges in a similar manner to the way that the gravitational field acts between two masses, and like it, extends towards infinity and shows an inverse square relationship with distance. However, there is an important difference. Gravity always acts in attraction, drawing two masses together, while the electric field can result in either attraction or repulsion. Since large bodies such as planets generally carry no net charge, the electric field at a distance is usually zero. Thus gravity is the dominant force at distance in the universe, despite being much weaker.

An electric field generally varies in space, and its strength at any one point is defined as the force (per unit charge) that would be felt by a stationary, negligible charge if placed at that point. The conceptual charge, termed a 'test charge', must be vanishingly small to prevent its own electric field disturbing the main field and must also be stationary to prevent the effect of magnetic fields. As the electric field is defined in terms of force, and force is a vector, so it follows that an electric field is also a vector, having both magnitude and direction. Specifically, it is a vector field.

The study of electric fields created by stationary charges is called electrostatics. The field may be visualized by a set of imaginary lines whose direction at any point is the same as that of the field. This concept was introduced by Faraday, whose term 'lines of force' still sometimes sees use.

The field lines are the paths that a point positive charge would seek to make as it was forced to move within the field; they are however an imaginary concept with no physical existence, and the field permeates all the intervening space between the lines. Field lines emanating from stationary charges have several key properties: first, that they originate at positive charges and terminate at negative charges; second, that they must enter any good conductor at right angles, and third, that they may never cross nor close in on themselves.

A hollow conducting body carries all its charge on its outer surface. The field is therefore zero at all places inside the body. This is the operating principal of the Faraday cage, a conducting metal shell which isolates its interior from outside electrical effects.

The principles of electrostatics are important when designing items of high-voltage equipment. There is a finite limit to the electric field strength that may be withstood by any medium.

Beyond this point, electrical breakdown occurs and an electric arc causes flashover between the charged parts. Air, for example, tends to arc across small gaps at electric field strengths which exceed 30 kV per centimeter. Over larger gaps, its breakdown strength is weaker, perhaps 1 kV per centimeter. The most visible natural occurrence of this is lightning, caused when charge becomes separated in the clouds by rising columns of air, and raises the electric field in the air to greater than it can withstand. The voltage of a large lightning cloud may be as high as 100 MV and have discharge energies as great as 250 kWh.

The field strength is greatly affected by nearby conducting objects, and it is particularly intense when it is forced to curve around sharply pointed objects. This principle is exploited in the lightning conductor, the sharp spike of which acts to encourage the lightning stroke to develop there, rather than to the building it serves to protect.

Electric Potential

The concept of electric potential is closely linked to that of the electric field. A small charge placed within an electric field experiences a force, and to have brought that charge to that point against the force requires work. The electric potential at any point is defined as the energy required to bring a unit test charge from an infinite distance slowly to that point. It is usually measured in volts, and one volt is the potential for which one joule of work must be expended to bring a charge of one coulomb from infinity. This definition of potential, while formal, has little practical application, and a more useful concept is that of electric potential difference, and is the energy required to move a unit charge between two specified points.

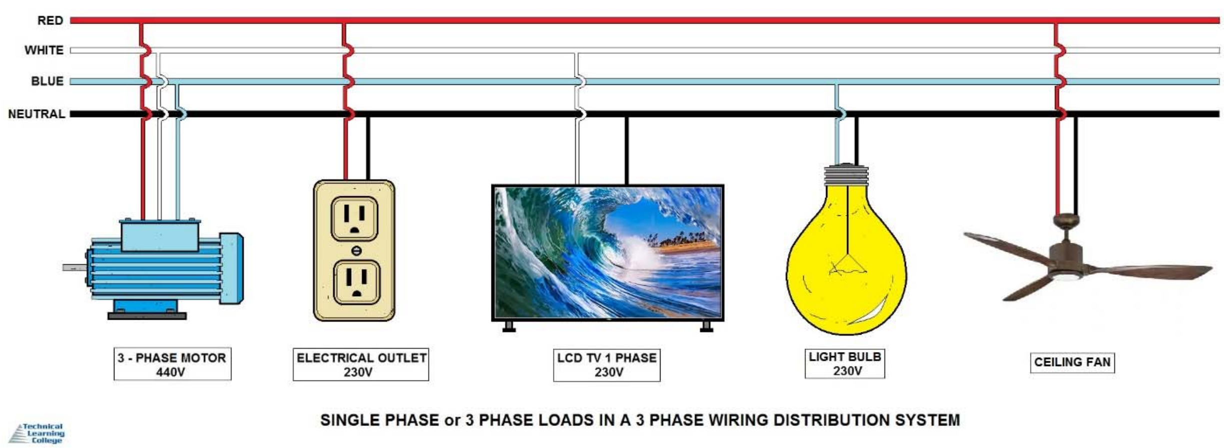
An electric field has the special property that it is conservative, which means that the path taken by the test charge is irrelevant: all paths between two specified points expend the same energy, and thus a unique value for potential difference may be stated. The volt is so strongly identified as the unit of choice for measurement and description of electric potential difference that the term voltage sees greater everyday usage.

For practical purposes, it is useful to define a common reference point to which potentials may be expressed and compared. While this could be at infinity, a much more useful reference is the Earth itself, which is assumed to be at the same potential everywhere. This reference point naturally takes the name earth or ground. Earth is assumed to be an infinite source of equal amounts of positive and negative charge, and is therefore electrically uncharged—and unchargeable.

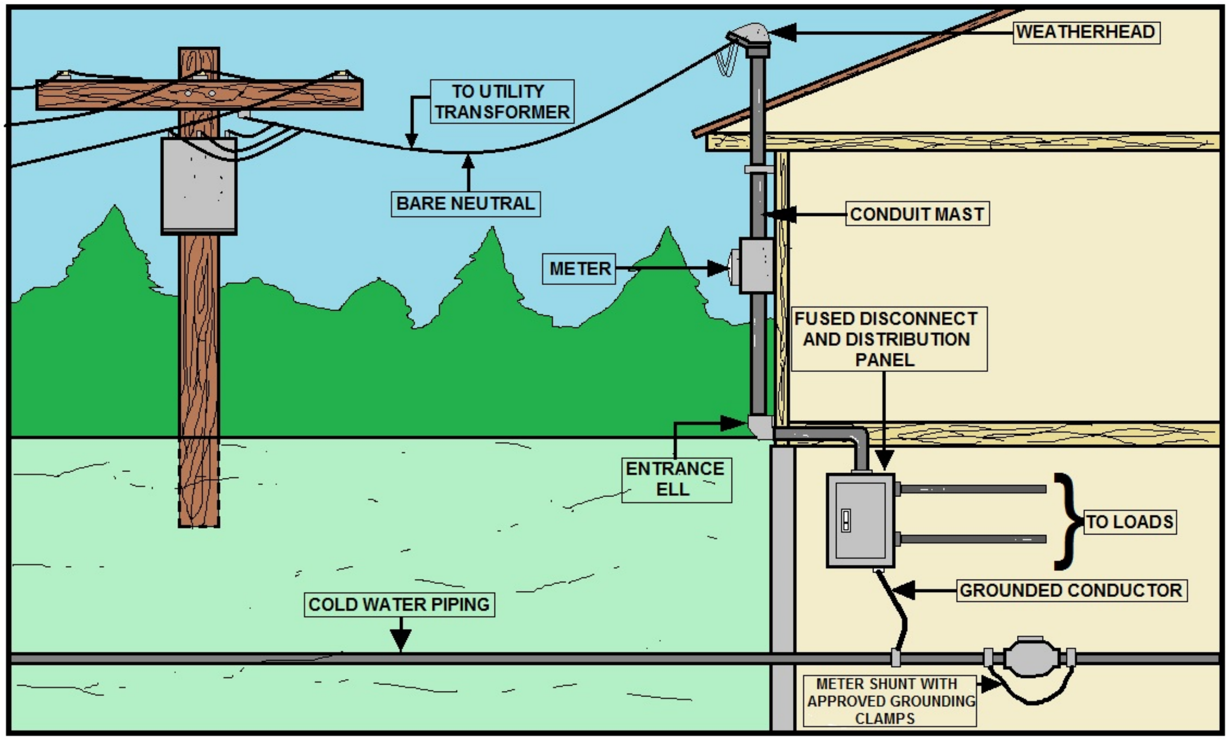
Electric potential is a scalar quantity, that is, it has only magnitude and not direction. It may be viewed as analogous to height: just as a released object will fall through a difference in heights caused by a gravitational field, so a charge will 'fall' across the voltage caused by an electric field.

As relief maps show contour lines marking points of equal height, a set of lines marking points of equal potential (known as equipotentials) may be drawn around an electrostatically charged object. The equipotentials cross all lines of force at right angles. They must also lie parallel to a conductor's surface; otherwise this would produce a force that will move the charge carriers to even the potential of the surface.

The electric field was formally defined as the force exerted per unit charge, but the concept of potential allows for a more useful and equivalent definition: the electric field is the local gradient of the electric potential. Usually expressed in volts per meter, the vector direction of the field is the line of greatest slope of potential, and where the equipotentials lie closest together.



SINGLE PHASE or 3 PHASE LOADS IN A 3 PHASE WIRING DISTRIBUTION SYSTEM



EXAMPLE OF A RESIDENTIAL TRANSFORMER CONNECTION

Technical Learning College

Section 6 – Classical Mechanics- Potential and Potential Difference Post Quiz

1. In engineering or household applications, _______________is often described as being either direct current (DC) or alternating current (AC). These terms refer to how the current varies in time.

2. Direct current, as produced by example from a battery and required by most electronic devices, is a _______________flow from the positive part of a circuit to the negative.

3. Alternating current is any current that reverses direction repeatedly; almost always this takes the form of a____________________.

4. Alternating current thus pulses back and forth within a conductor without the charge moving any net distance over time. The time-averaged value of an alternating current is_______________, but it delivers energy in first one direction, and then the reverse.

5. ___________________is affected by electrical properties that are not observed under steady state direct current, such as inductance and capacitance. These properties however can become important when circuitry is subjected to transients, such as when first energized.

6. An electric field generally varies in space, and its strength at any one point is defined as the force (per unit charge) that would be felt by a _______________charge if placed at that point.

7. The conceptual charge, termed a_________________, must be vanishingly small to prevent its own electric field disturbing the main field and must also be stationary to prevent the effect of magnetic fields.

8. As the ______________is defined in terms of force, and force is a vector, so it follows that an electric field is also a vector, having both magnitude and direction. Specifically, it is a vector field.

9. The _______________are the paths that a point positive charge would seek to make as it was forced to move within the field; they are however an imaginary concept with no physical existence, and the field permeates all the intervening space between the lines.

10. The principles of electrostatics are important when designing items of high-voltage equipment. There is a _____________limit to the electric field strength that may be withstood by any medium.

Section 6- Post Quiz Answers

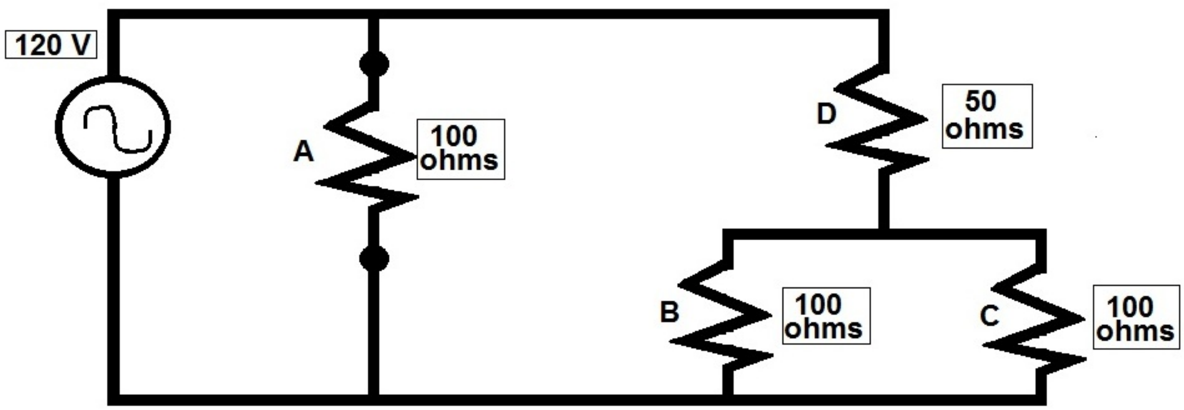
1. Current
2. Unidirectional
3. Sine wave
4. Zero
5. Alternating current
6. Stationary, negligible
7. 'Test charge'
8. Electric field
9. Field lines
10. Finite

Section 7 – Circuits, Coils and Capacitors

Section Focus: You will learn advanced electrical theories and laws. At the end of this section, you will be able to understand and describe electrical circuits, coils and capacitors. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: In order to understand electrical principles, we first need to explain the various simple forms of electrical currents. Because this area of study is quite large and detailed, we will only focus upon electrical circuits, coils and capacitors.

We will examine the relationships between current, voltage, and resistance in series and parallel circuits, current and voltage in capacitors and inductors, and explain the practical effects of impedance and reactance in circuits.



Practice Exercise

1. What is the equivalent resistance of this circuit?" _______________

2. What is the total current drawn? _________

3. What is the voltage across each branch in the original circuit?

Branch A _________

Branch B-C _________

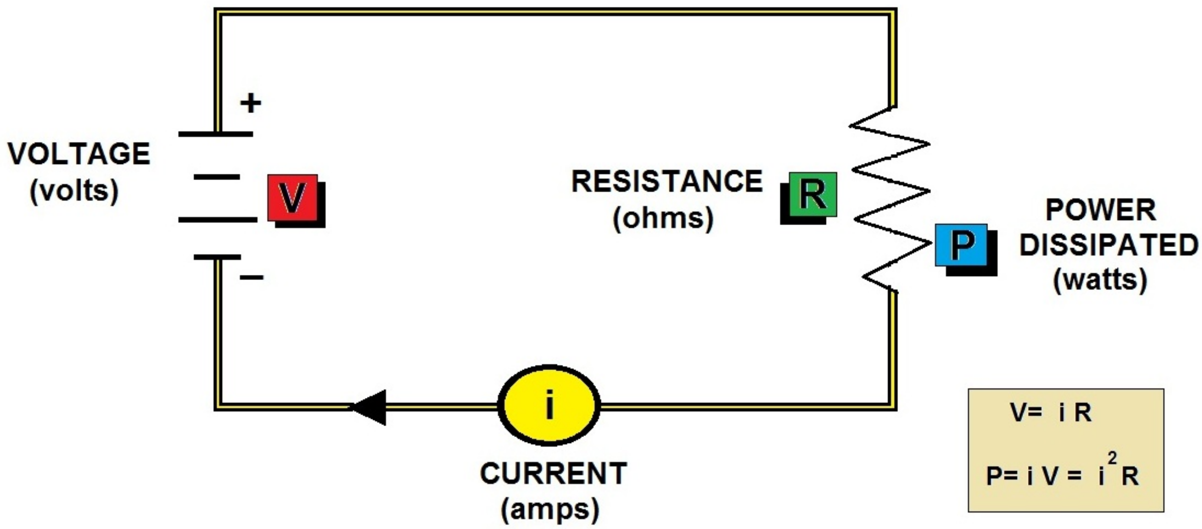
Branch D _________

4. In this circuit, how much power is being consumed? _________

Except for new super conductors, any material that electric current flows in has resistance.

Whenever current flows in a resistance, the voltage across the resistance in volts equals the current in amperes times the resistance in ohms (E = I X R).

This is Ohm's Law.

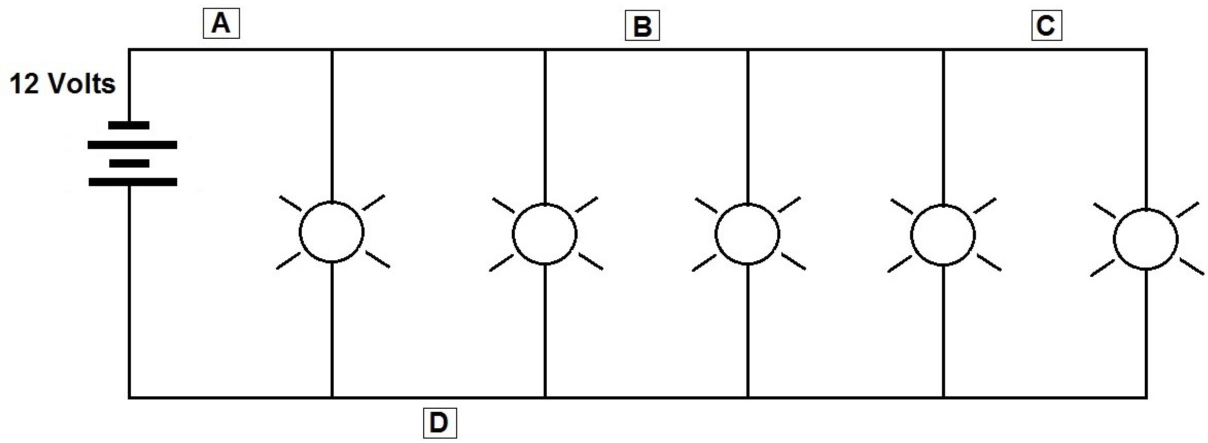


Ohm's Law

Ohm's Law can be used to understand the behavior of electricity in individual components as well as in entire circuits. However, using Ohm's Law correctly - depends upon understanding the differences between the two common electrical circuit arrangements, Series Circuits and Parallel Circuits.

Series Circuit- Introduction

In a series circuit, the components are connected end-to-end, so that all the electrons that leave the source in a current pass through all the components, one after the other, before returning to the source. The same current, in amperes, flows through all the loads.

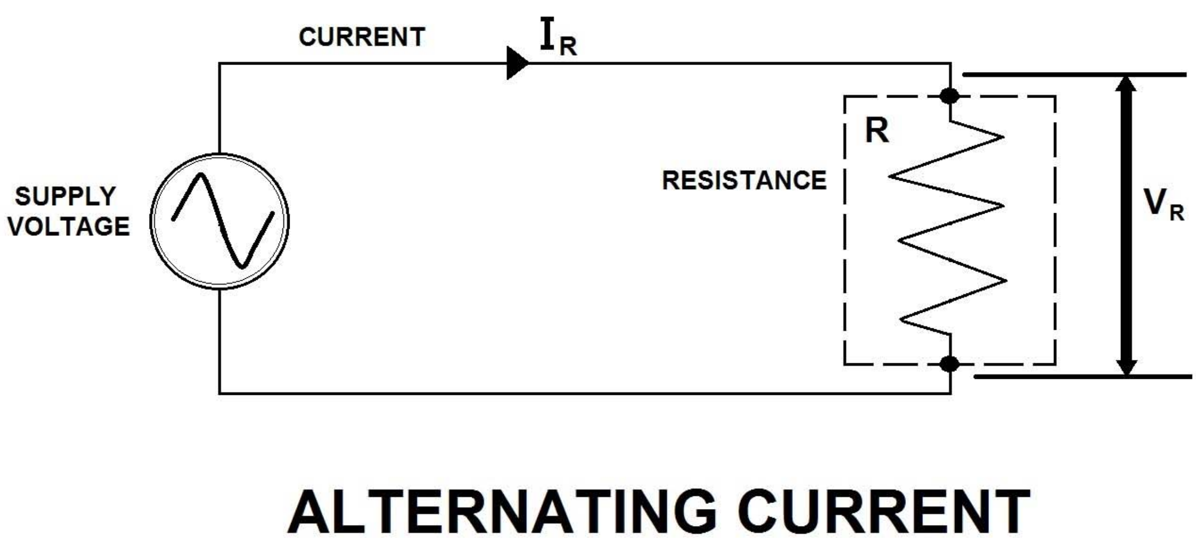


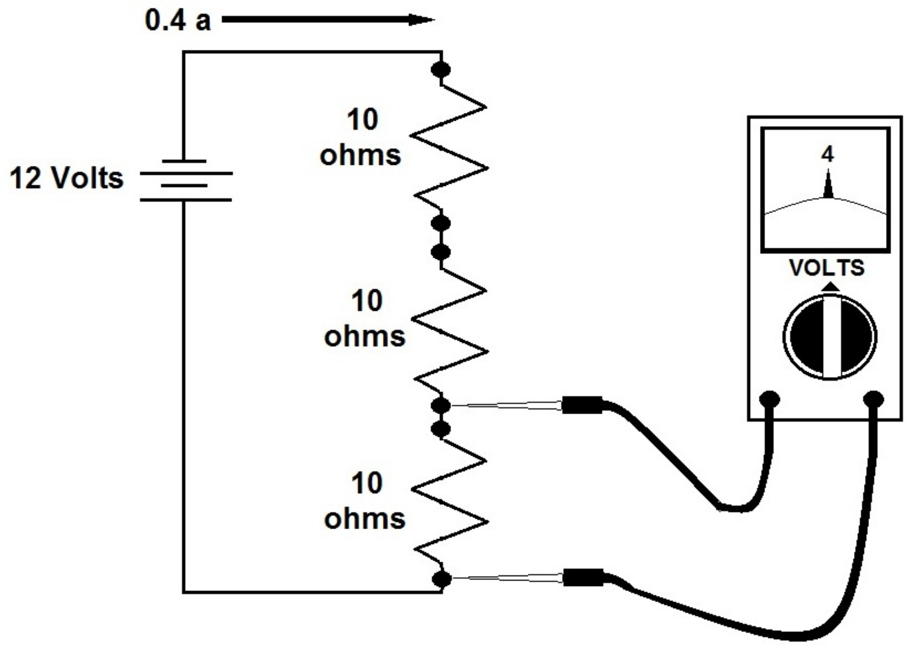
(The above is a Parallel circuit not a Series circuit.)

If the current is interrupted anywhere in the circuit (an "open circuit"), no current will flow anywhere.

This is what happens when a switch is opened, or when one of the loads burns out; all the loads will stop working, since there is no way for the current to complete the circuit back to the source.

The circuit current depends, according to Ohm's Law, on the source voltage and the resistance of the circuit. The resistance of a series circuit is the sum of the resistance of all the loads.

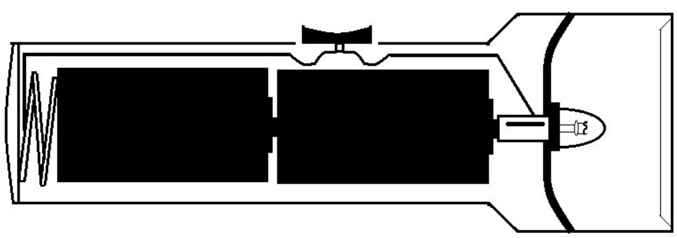




In this example, three 10 ohm loads are connected in series. The total resistance of the circuit is 10 + 10 + 10 = 30 ohms.

The 12 volt battery will push 12 volts/30 ohms = 0.4 amperes through all the loads.
Ohm's Law also applies to each individual resistor. 0.4 amperes through a 10 ohm resistor produces a voltage drop of 4 volts.

The voltage drop across these three ten ohm resistors is 4 + 4 + 4 = 12 volts. In a series circuit, the voltage drops across each load add up to the source voltage.



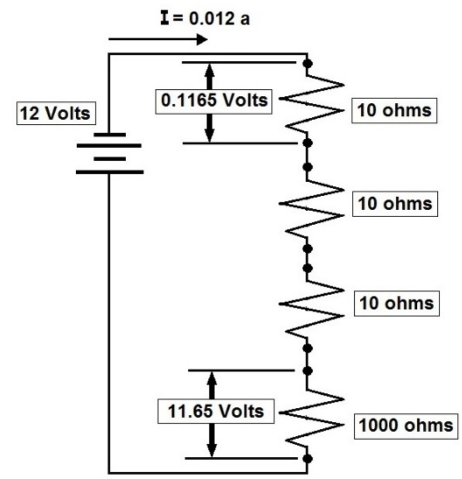
Practice Exercise
In a two-cell flashlight, each cell produces 1.5 volts. The 'switch is on, but the contacts are seriously corroded and have a resistance of 5 ohms. The bulb resistance is 1 ohm.

1. Voltage measured across the cells will be --________

2. Voltage measured across the switch will be --________

3. Voltage measured across the bulb will be --________

R, I and V in Series Circuits

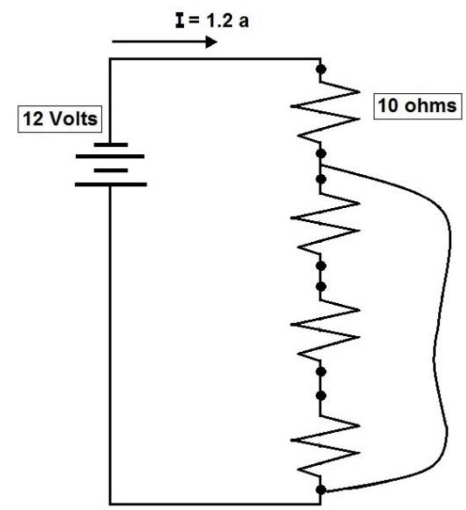


• If we add a 1000 ohm load to the previous circuit:
Total circuit resistance will be 1030 ohms.
Total circuit current will be
12 volts/1 030 ohms = 0.01165 amperes.

Voltage drop across each 1 0 ohm load is
0.01165 amperes x 10 ohms = 0.1165 volts.

Voltage drop across the 1000 ohm load is
0.01165 amperes x 1000 ohms = 11.65 volts.

The voltage drops across all the loads still add up to the source voltage, 12 volts. Notice that practically all of the source voltage is across the 1000 ohm resistor. Voltage drop is proportional to resistance.

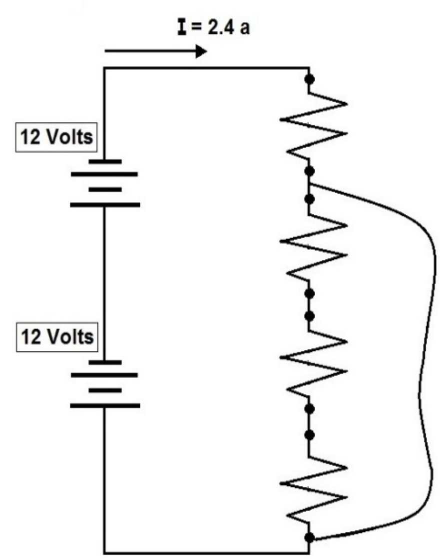


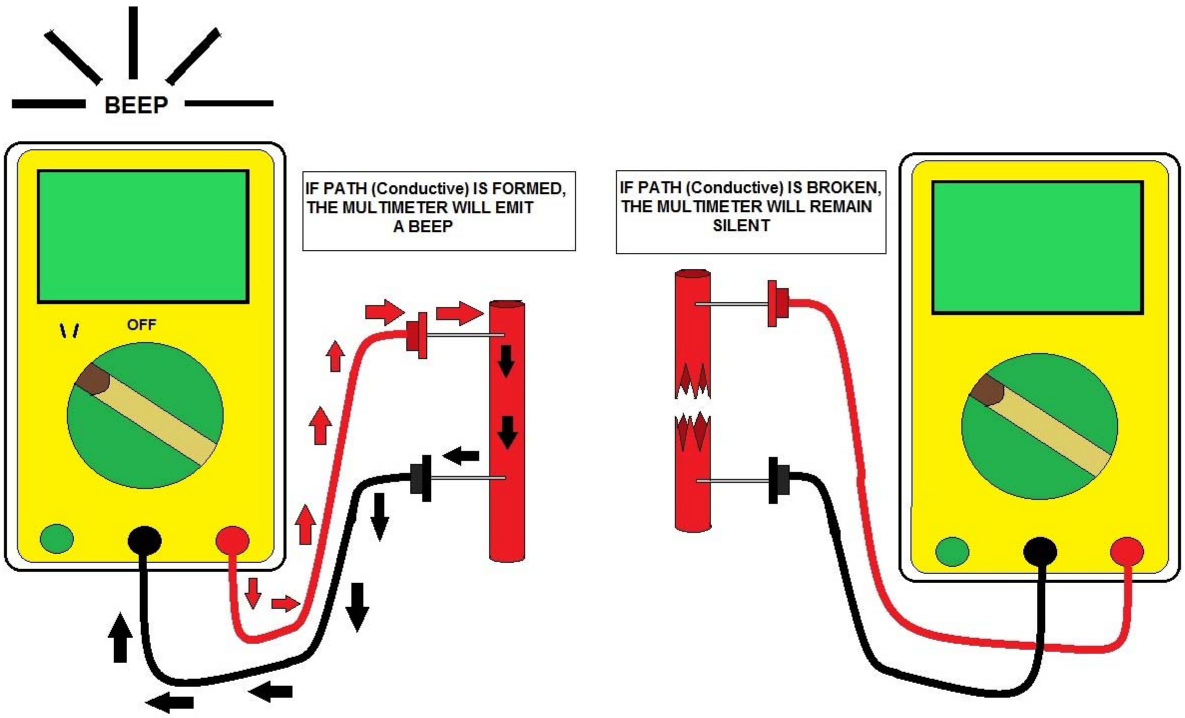
• If we "short out" all but one of the 10 ohm loads with a wire around them:
The current in the 10 ohm load, and the rest of the circuit, will be simply 12 volts/1 0 ohms = 1.2 amperes. The total source voltage will be across this one load.

The current in the other loads, and the voltage across them will be practically zero, since the total circuit current of 1.2 amperes is going through the low resistance wire instead of the loads; they are out of the circuit.

• If we add another source in series:
The total resistance of the circuit is the same. But the source voltage is doubled, since the electrons go through a 12 volt potential rise in the first source and another 12 volt potential rise in the second.

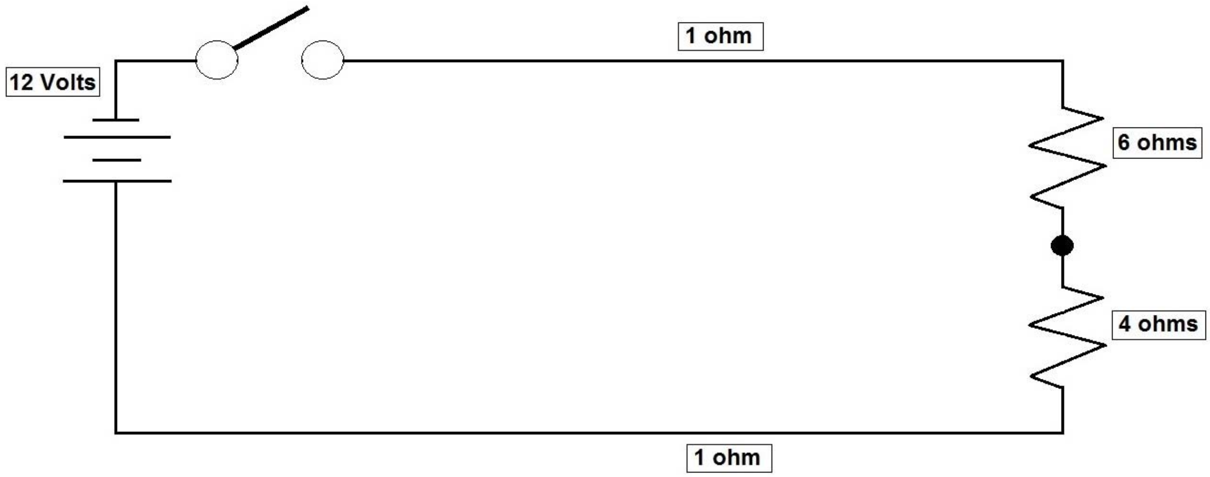
The circuit current will be 24 volts/1 0 ohms. 2.4 amperes will flow through the one 10 ohm resistor, both sources in series, and the wires connecting all the components.





MUTLTIMETER CONTINUITY TEST

Practical Exercise



In the circuit above, what is

1. the voltage across each load when the switch is open?__________

2. the current through the switch when the switch is closed? __________

3. the voltage drop in the conductors between the source and the load? __________

4. the voltage drop across each load? __________

Disadvantages of Series Circuits
Loads are seldom connected in series because:

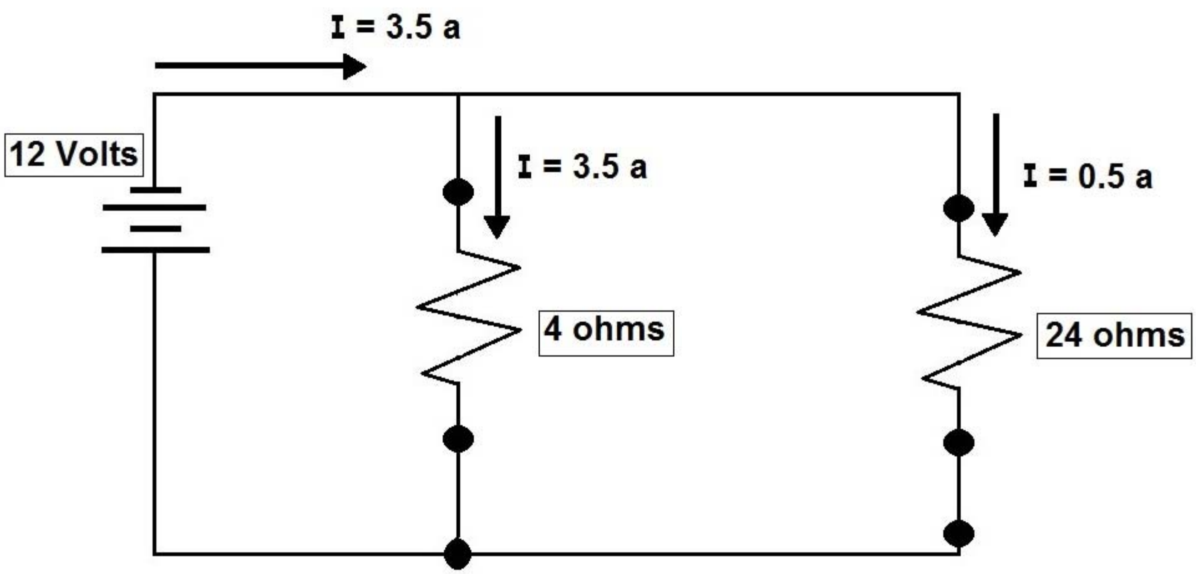
- loads cannot be individually controlled.
- one burnt out load shuts down the whole circuit.
- since current is the same throughout the circuit, all loads must be rated for the same current.
- and, as you can see from the last Practice Exercise, voltage divides between loads, making it difficult to provide the proper voltage to all loads.

Parallel Circuits

Loads are normally arranged in parallel with each other:

- Loads can operate and be controlled individually.
- If one load burns out the others are not affected.
- The voltage across each load is source voltage, so each load receives the voltage it requires.
- The current in each branch is determined by the resistance of the load in that particular branch, so loads of different amperage ratings may be used in the circuit.

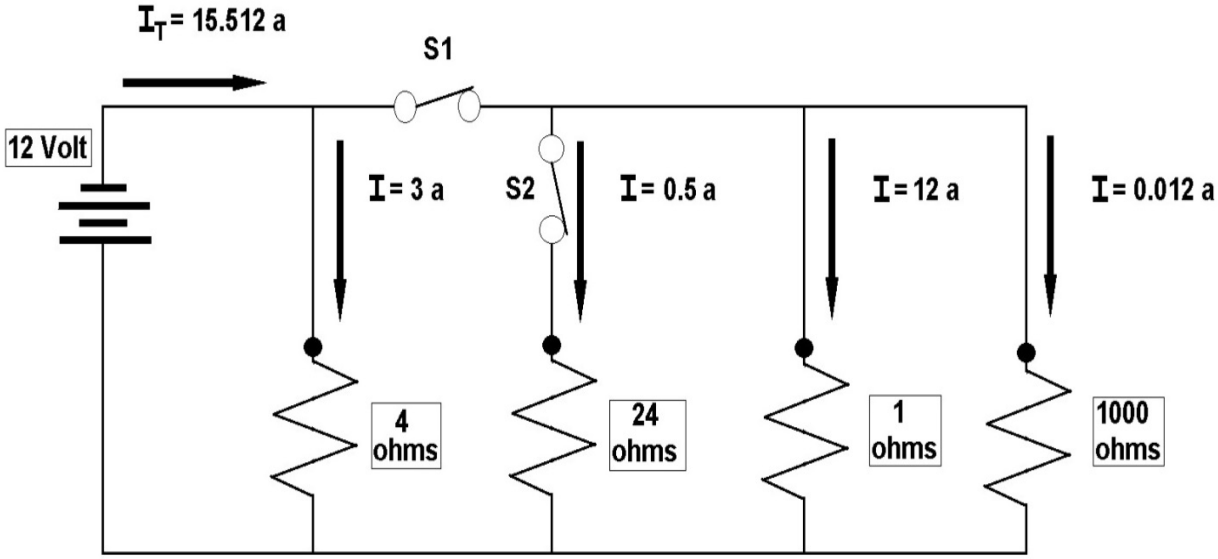
Current in Parallel Circuits
In a parallel circuit, the current drawn from the source is the sum of the currents in all of the loads.



Ohm's Law allows us to find the current in each individual load.

In this example, the current in the 4 ohm load is the system voltage, 12 volts, divided by 4 ohms, or 3 amperes. The current in the 24 ohm load is 12 volts/24 ohms = 0.5 amperes. The total current from the source is 3 + 0.5 = 3.5 amperes.

What happens if we change the Circuit?

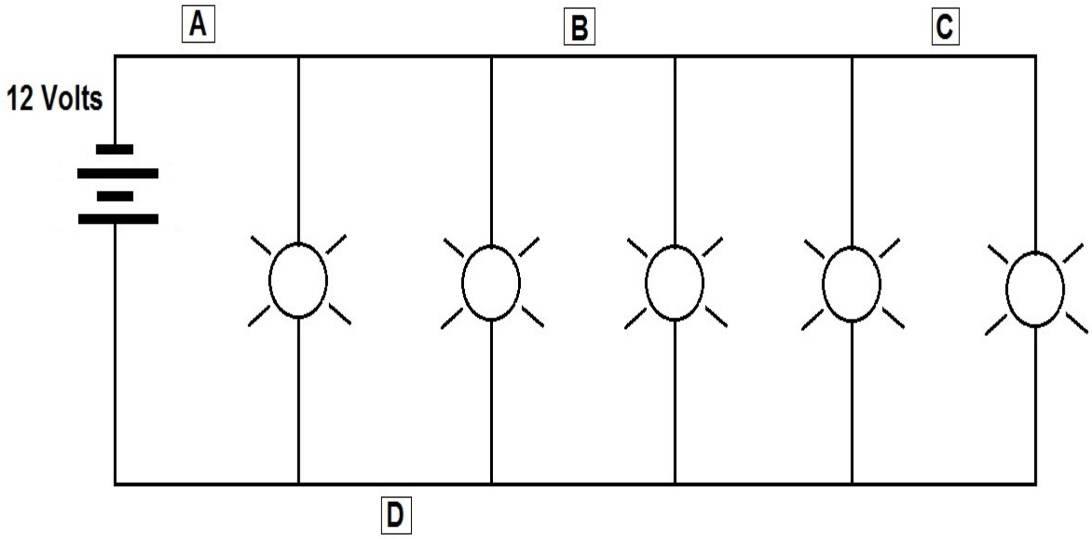


A. Suppose a 1 ohm load and a 1000 ohm load are added in parallel with the 4 ohm and the 24 ohm loads. The current in the 1 ohm load will be 12 volts/1 ohm = 12 amperes. The current in the 1000 ohm load will be 12 volts/1 000 ohms = 0.012 amperes. The total circuit current will now be 3 + 0.5 + 12 + 0.012 = 15.512 amperes.

B. Suppose the 24 ohm load burns out. The current in the load will drop to zero, and the total circuit current drops to 15.512 - 0.5 = 15.012.

C. Suppose switch 1 is opened. AU loads but the 4 ohm load are cut off from source voltage. The 4 ohm load is not affected. Source current drops to 3 amperes.

D. Suppose switch 2 is opened. The 24 ohm load only is turned off. The effect is the same as in B.



Practice Exercise
A 12 volt battery supplies five 4-watt indicator lights in parallel. What is the current at points A, B, C, and 0 when all the lights are on?

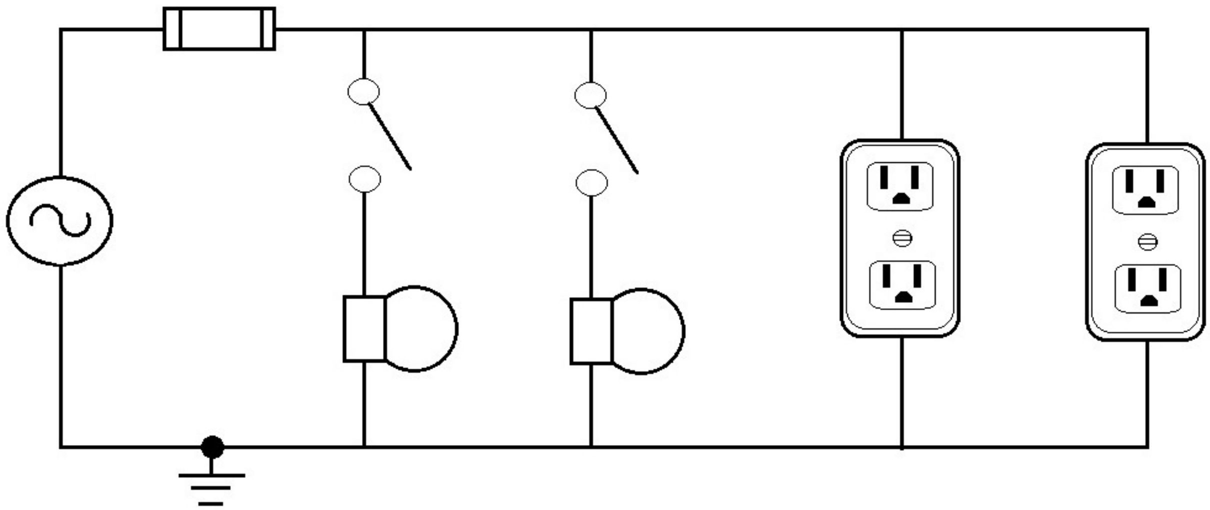
Point A = ______ amperes

Point B = ______ amperes

Point C = ______ amperes

Point D = ______ amperes

Circuit Protection in Parallel Circuits



TYPICAL HOUSEHOLD RECEPTACLE AND LIGHT CIRCUIT

This is a typical general purpose household receptacle and light circuit.

One fuse, at the source, and in series with the parallel combination of loads, protects all circuit components and conductors.

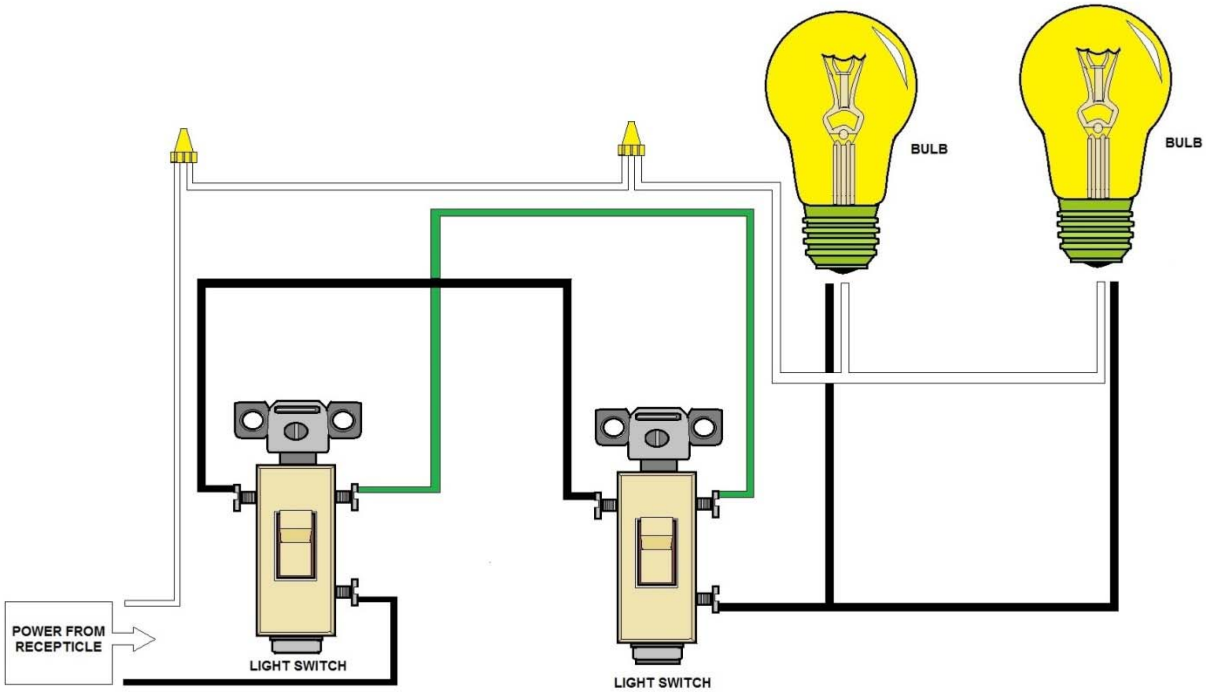
If a load which took all of the rated fuse current was plugged into any receptacle, all the wires connecting the fuse and that receptacle would be carrying the maximum circuit current.

So ALL the wires in this kind of circuit must be capable of carrying the full rated fuse current without damage.

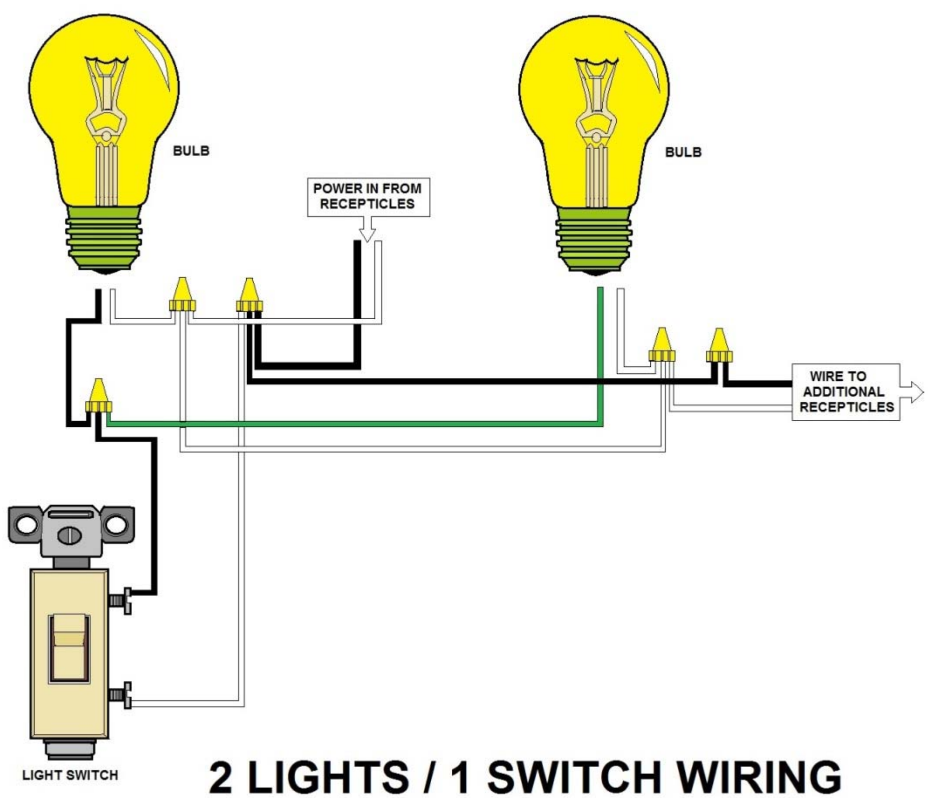
Notice that the fuse is inserted in series with the supply conductor right at the source, so that it can protect every wire in the circuit. Notice also that the fuse is in the hot conductor, not the grounded conductor. This is to ensure that there is no voltage on any lines after it blows.

Grounded conductors must not be fused.

Switches also are always wired to interrupt the hot conductor, rather than the grounded conductor, so components that are switched off will have no voltage on them.



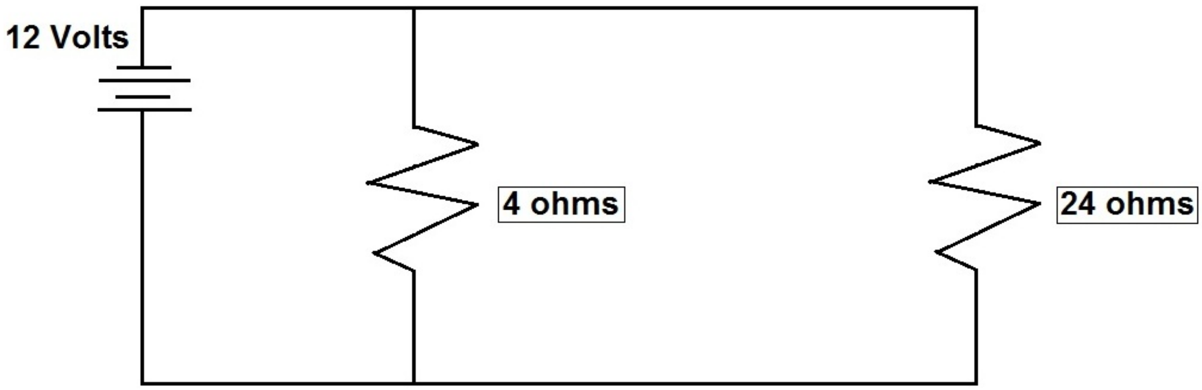
3-WAY LIGHT SWITCH WIRING



2 LIGHTS / 1 SWITCH WIRING

Resistance in Parallel Circuits

Unlike a series circuit, the total resistance of a parallel circuit is NOT the sum of the load resistances. The resistance of this circuit is NOT 4 ohms + 24 ohms = 28 ohms. It is actually 3.43 ohms - which is less than the smallest resistance in the circuit.



The formula commonly used to calculate the total resistance (R_T) of loads wired is

$$R1 = \frac{1}{\frac{1}{R_1} \quad \frac{1}{R_2} \quad \frac{1}{R_3}}$$

In this formula, the resistance *at* each load in the circuit is represented by R1, R2, R3 and so on. To find the total resistance of a parallel circuit, divide 1 by each resistance, then add your answers together. This total is the total conductance of then circuit, measured in siemens. Once you know the total conductance, divide 1 by that total to get the total resistance.

These calculations can be done with a pocket calculator in three steps. For example, in the above circuit:

Divide 1 by each resistance. Using a pocket calculator automatically gives you a decimal number.

1 ÷ 4 = .25
1 ÷ 24 = .0416

Add the decimal numbers together. (This is the total conductance, in siemens.)

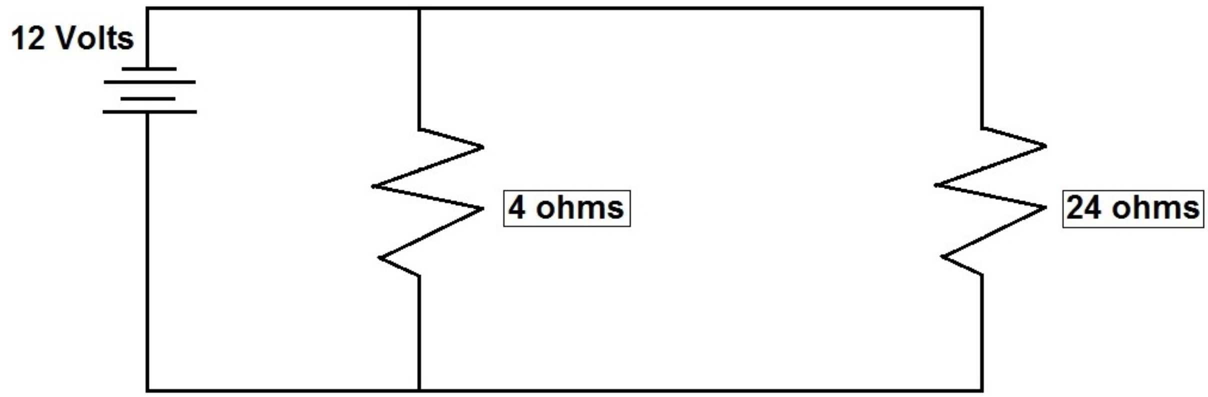
.25 ÷ .0416 = .2916

Divide 1 by your answer. (This is the total resistance, in ohms.)

1 ÷ .2916 = 3.4282

3.428 ohms is the total resistance of the circuit.

Conductance is a measure of how much current a circuit will conduct. It is the reciprocal of the resistance. This means, for example, that a 4-ohm resistor has a conductance of 1/4 or .25 siemen. To find the total conductance of a circuit, add together the individual conductances.



$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots}$$

$1 \div 4 = .25$

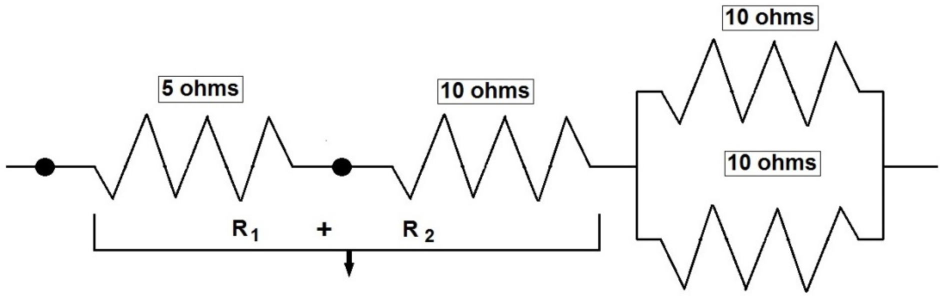
$1 \div 24 = .0416$

$.25 + .0416 = .2916$

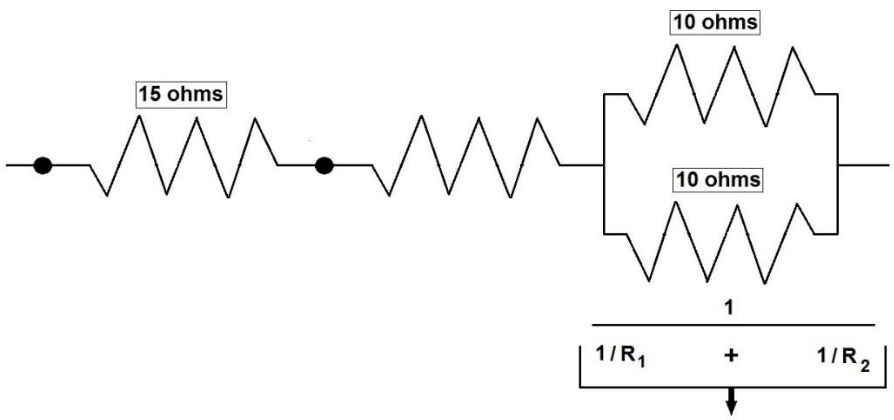
$1 \div .2916 = 3.4282$

Equivalent Circuits

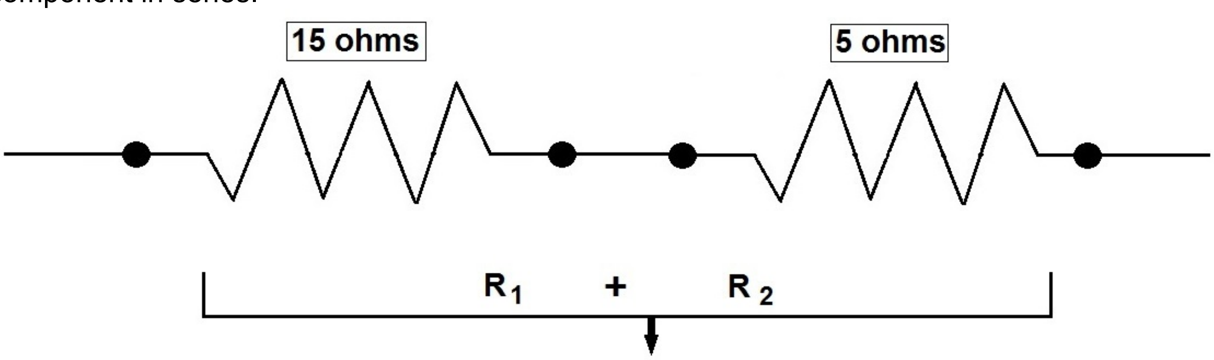
Frequently, complex circuits include components in both series *and* parallel. To figure fuse or conductor size, it is often necessary to find the total current. Usually, the easiest way to do this is to reduce the circuit to a single, equivalent load, and calculate the current in it. The procedure involves several steps:



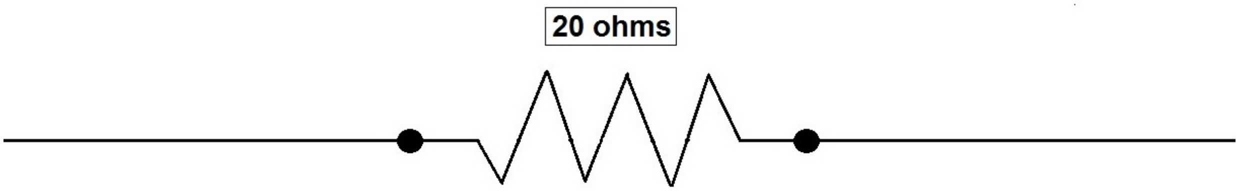
1. First, replace any two components that are connected in series with a single component having a resistance equal to the sum of their resistances. In other words, if you find two components joined together in series, and nothing else is connected to their junction, add their resistances and replace them with a single equivalent component.



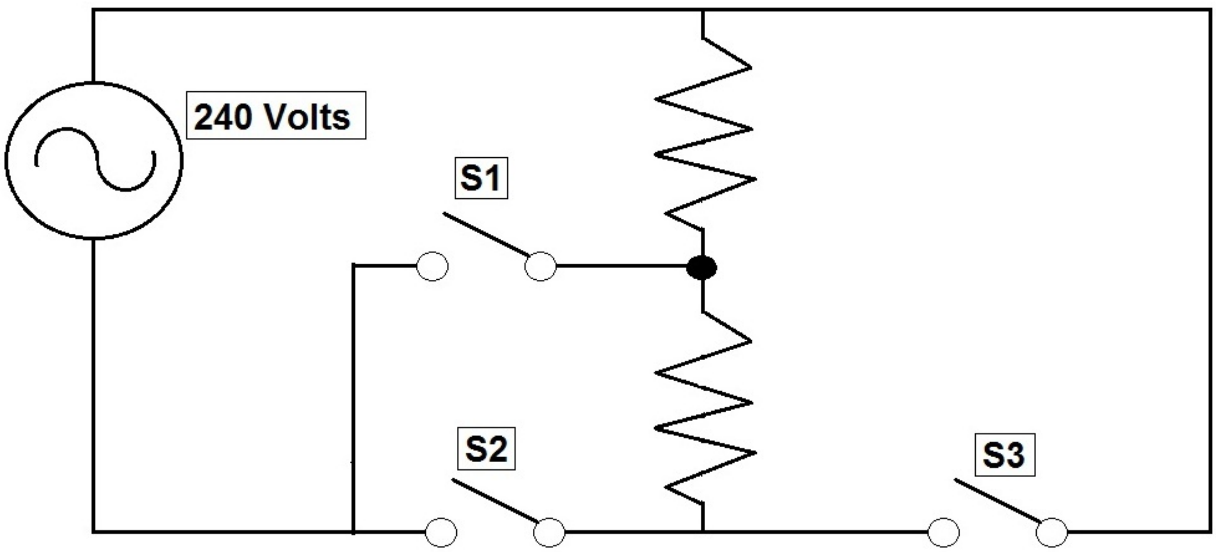
2. Second, replace any two components that are connected in parallel with a single component having a conductance equal to the sum of their conductances. You will need to convert the equivalent conductance back into a resistance before adding it to the resistance of another component in series.



3. Repeat this procedure as often as necessary until all component combinations have been replaced with one equivalent.



Practice Exercise



Two oven elements are arranged with three switches to provide three heat settings: high, medium, and low. In low, the two elements are connected in series between 240 volts. In medium, one is connected to 240 volts and the other is not connected. In high, both elements are connected across 240 volts in parallel.

A. Circle the switch or switches which must be closed in each setting.

Low: 1,2,3

Medium: 1, 2, 3

High: 1,2,3

B. Which switches must never be closed at the same time? Why?

Impedance and Resistance Section

In AC and DC circuits containing purely resistive loads, like lights and heaters, Ohm's Law may be applied to figure current, voltage and resistance. However, when AC circuits contain coils or capacitors, the behavior of current and voltage is altered.

For example, you might measure the resistance of a coil to be 2 ohms. According to Ohm's Law, you would expect 12 amperes to flow when you put 24 volts across the coil--and this is what you would measure if the 24 volts was DC. If it is AC, however, and you measure the current, you'll find it is much less. Ohm's Law does not seem to be working.

IMPEDANCE = RESISTANCE AND REACTANCE.

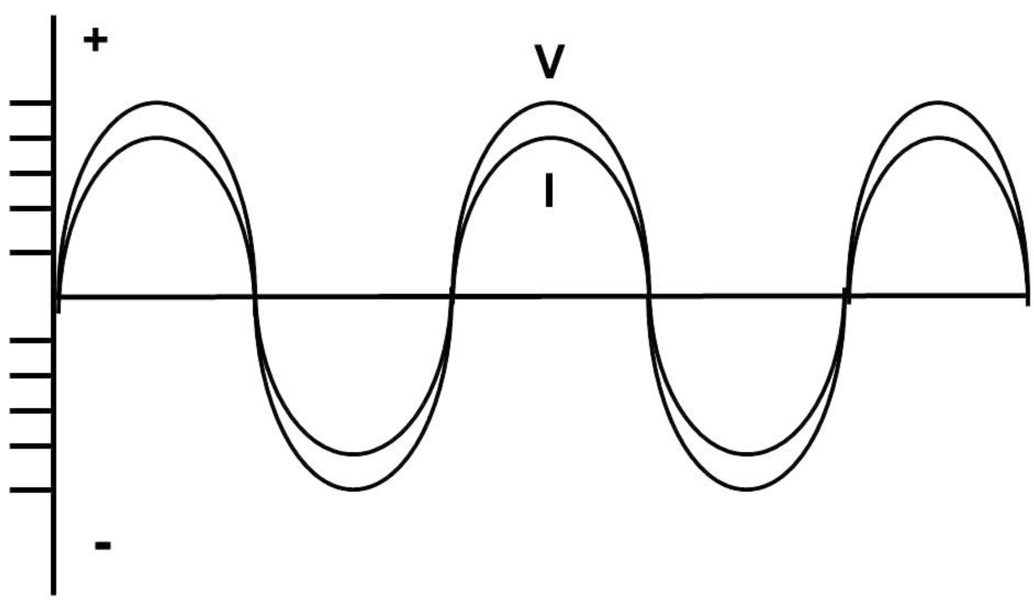
The reason is that coils and capacitors in AC circuits oppose the flow of current with a force called Reactance. Both reactance and resistance impede current in these circuits.

The term Impedance, represented by the letter Z, is used to include both reactance and resistance, and replaces the "R" in Ohm's Law.

$$Z = V / I$$

The impedance, Z, of a component or a circuit is its total opposition to current flow.

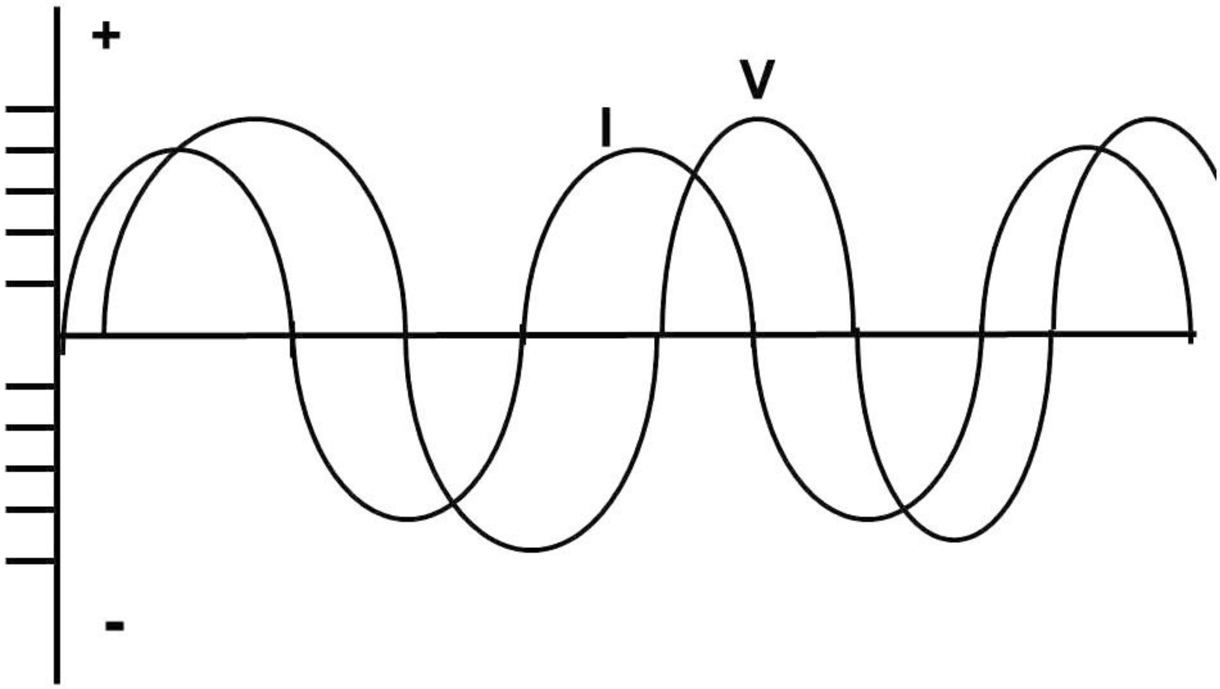
Resistance
When alternating voltage is applied to any resistive component, the current produced alternates exactly in step with the Voltage.



Both current and voltage follow a sine wave pattern, with the positive and negative voltage and current peaks occurring at exactly the same time.

Inductive Reactance

In coils, or inductors, current lags behind voltage by 90°.



Electromagnetic inductance, as we saw in Lesson 2, is the generation of a voltage whenever current changes its value in a wire. When the wire is coiled, the effect is intensified.

The voltage induced in a coil is called Counter EMF. It's polarity is opposite to the polarity of the applied voltage, so it actually works against the applied voltage and opposes the change in current level. Counter EMF can be pictured as a force that current must overcome. The effect is that current is slowed down in relation to applied voltage Its flow is impeded, and it falls behind the applied voltage.

This is the formula for calculating the inductive reactance of a coil:

$$X_L = 6.28 \times f \times L$$

In cases where the resistance of a coil is low, X is also the impedance, in, Ohms, of the coil, since the low resistance may be ignored. L is the inductance of the coil, measured in Henrys. The larger the diameter of the coil, and the more turns it has, the higher its inductance will be.

f stands for the AC frequency, normally either 50 -or 60 Hertz.

Practice Exercise

1. A coil is rated at 500 millihenrys and will be used in a 60 Hertz circuit. What will its impedance be?

2. The voltage across a coil in a 50 hertz circuit is 240v. An ammeter indicates that 3 amperes of current are flowing through it. What is its impedance?

Combining Impedances in Series and Parallel

Earlier, we saw how to combine series and parallel resistances into a single equivalent resistance.

The same procedure will work to combine reactance in any series or parallel circuit if the components are all" capacitors. or all coils. In other words:

1. to find an equivalent reactance for the inductive reactance of coils in series, and capacitors in series, add their reactances.

2. to find an equivalent reactance for parallel reactances, divide them into 1, add the results, and then divide the results into 1 again for an equivalent single reactance.

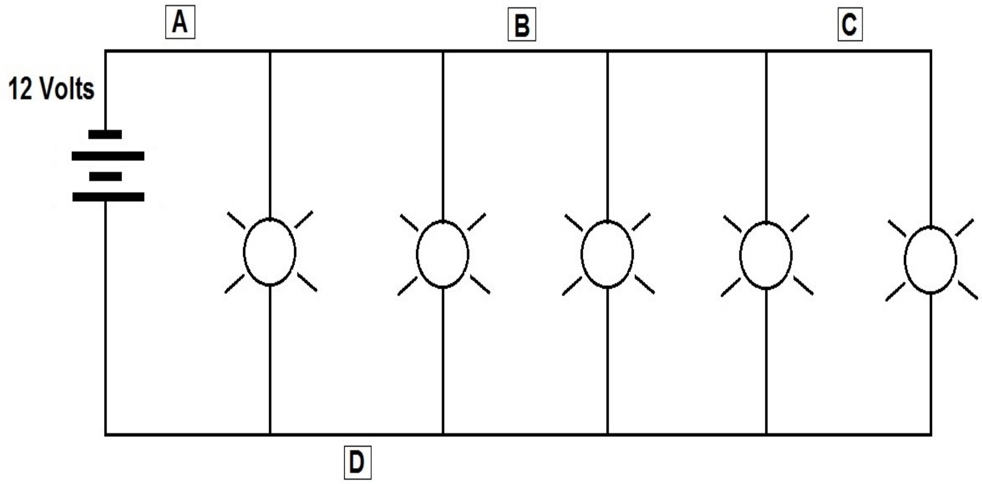
In circuits where coils, capacitors, and resistors are mixed, the procedure is more complicated, since voltage and current are in-phase in resistance, and out-of-phase in the opposite direction in capacitors and coils.

Practical Exercise

Assume 60 cycle AC:
1. What is the reactance of this series combination of two 2 millihenry coils?

2. What is the current from the source in this circuit of two 10 microfarad capacitors in parallel? Note: 1 farad = 1,000,000 microfarads.

Section 7 – Circuits, Coils and Capacitors Post Quiz



A 12-volt battery supplies five 4-watt indicator lights in parallel. What is the current at points A, B, C, and 0 when all the lights are on?

1. Point A = ______ amperes

2. Point B = ______ amperes

3. Point C = ______ amperes

4. Point D = ______ amperes

5. A coil is rated at 500 millihenrys and will be used in a 60 Hertz circuit. What will its impedance be?

6. The voltage across a coil in a 50 hertz circuit is 240v. An ammeter indicates that 3 amperes of current are flowing through it. What is its impedance?

Assume 60 cycle AC:
7. What is the reactance of this series combination of two 2 millihenry coils?

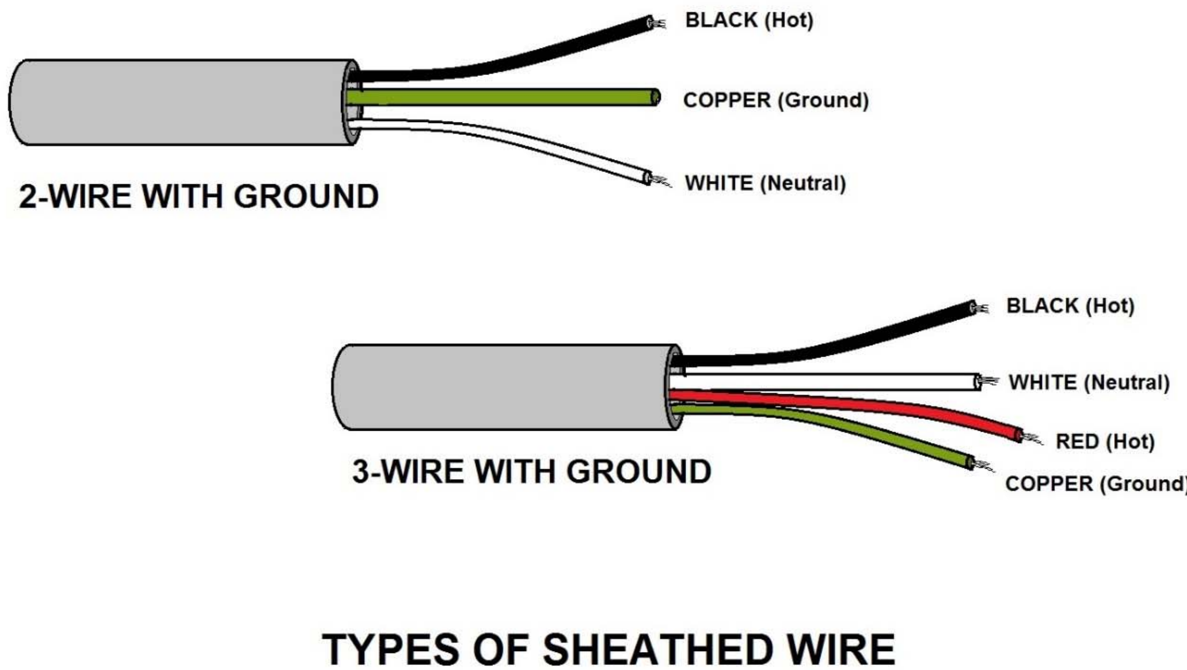
8. What is the current from the source in this circuit of two 10 microfarad capacitors in parallel? Note: 1 farad = 1,000,000 microfarads.

Section 8 – Power and Phases

Section Focus: You will learn advanced electrical theories and laws. At the end of this section, you will be able to understand and describe various power phases, single, double and three phases. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: In order to understand electrical principles, we first need to explain the various simple forms of electrical currents. Because this area of study is quite large and detailed, we will only focus on single, double and three phases.

Understanding Single-Phase Power



Single-Phase Supply

In electrical engineering, single-phase electric power refers to the distribution of alternating current electric power using a system in which all the voltages of the supply vary in unison. Single-phase distribution is used when loads are mostly lighting and heating, with few large electric motors. A single-phase supply connected to an alternating current electric motor does not produce a revolving magnetic field; single-phase motors need additional circuits for starting, and such motors are uncommon above 10 or 20 kW in rating.

In contrast, in a three-phase system, the currents in each conductor reach their peak instantaneous values sequentially, not simultaneously; in each cycle of the power frequency, first one, then the second, then the third current reaches its maximum value.

The waveforms of the three supply conductors are offset from one another in time (delayed in phase) by one-third of their period. When the three phases are connected to windings around the interior of a motor stator, they produce a revolving magnetic field; such motors are self-starting.

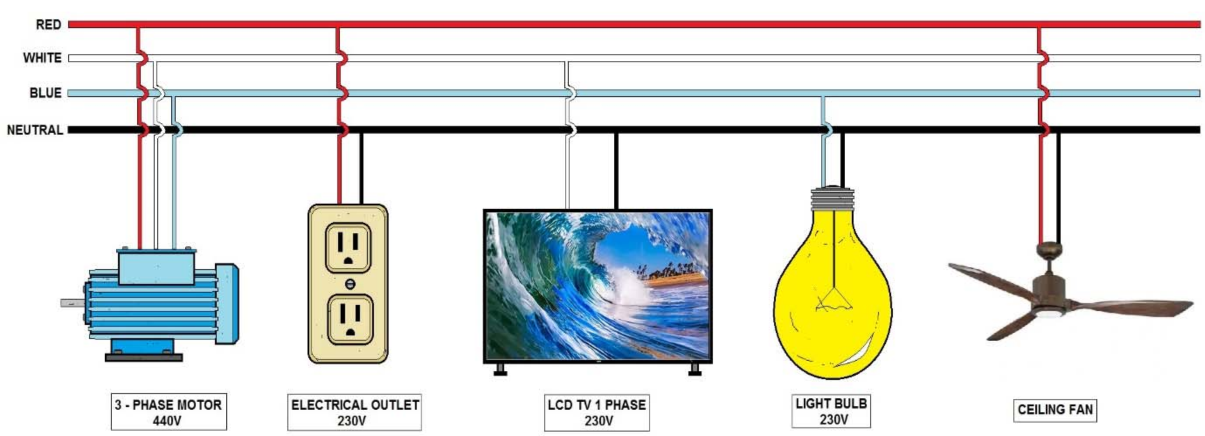
Standard Frequencies of Single-Phase Power

Standard frequencies of single-phase power systems are either 50 or 60 Hz. Special single-phase traction power networks may operate at 16.67 Hz or other frequencies to power electric railways. In some countries such as the United States, single phase is commonly divided in half to create split-phase electric power for household appliances and lighting. Single-phase power distribution is widely used especially in rural areas, where the cost of a three-phase distribution network is high and motor loads are small and uncommon.

High power systems, say, hundreds of kVA or larger, are nearly always three phase. The largest supply normally available as single phase varies according to the standards of the electrical utility. In the UK a single-phase household supply may be rated 100 A or even 125 A, meaning that there is little need for 3 phase in a domestic or small commercial environment.
Much of the rest of Europe has traditionally had much smaller limits on the size of single phase supplies resulting in even houses being supplied with 3 phase (in urban areas with three-phase supply networks).

In North America, individual residences and small commercial buildings with services up to about 100 kVA (417 amperes at 240 volts) will usually have three-wire single-phase distribution, often with only one customer per distribution transformer. In exceptional cases larger single-phase three-wire services can be provided, usually only in remote areas where poly-phase distribution is not available.

In rural areas farmers who wish to use three-phase motors may install a phase converter if only a single-phase supply is available. Larger consumers such as large buildings, shopping centers, factories, office blocks, and multiple-unit apartment blocks will have three-phase service. In densely populated areas of cities, network power distribution is used with many customers and many supply transformers connected to provide hundreds or thousands of kVA, a load concentrated over a few hundred square meters.



SINGLE OR THREE PHASE LOADS IN A THREE PHASE WIRING SYSTEM

Three-Phase Power-Introduction

Three-phase electric power is a common method of alternating-current electric power generation, transmission, and distribution. It is a type of polyphase system and is the most common method used by electrical grids worldwide to transfer power. It is also used to power large motors and other heavy loads. A three-phase system is generally more economical than others because it uses less conductor material to transmit electric power than equivalent single-phase or two-phase systems at the same voltage. The three-phase system was introduced and patented by Nikola Tesla in 1887 and 1888.

In a three-phase system, three circuit conductors carry three alternating currents (of the same frequency) which reach their instantaneous peak values at different times. Taking one conductor as the reference, the other two currents are delayed in time by one-third and two-thirds of one cycle of the electric current. This delay between phases has the effect of giving constant power transfer over each cycle of the current and also makes it possible to produce a rotating magnetic field in an electric motor.

Three-phase systems may have a neutral wire. A neutral wire allows the three-phase system to use a higher voltage while still supporting lower-voltage single-phase appliances. In high-voltage distribution situations, it is common not to have a neutral wire as the loads can simply be connected between phases (phase-phase connection).

Three-phase has properties that make it very desirable in electric power systems:

- ✓ The phase currents tend to cancel out one another, summing to zero in the case of a linear balanced load. This makes it possible to eliminate or reduce the size of the neutral conductor; all the phase conductors carry the same current and so can be the same size, for a balanced load.
- ✓ Power transfer into a linear balanced load is constant, which helps to reduce generator and motor vibrations.
- ✓ Three-phase systems can produce a magnetic field that rotates in a specified direction, which simplifies the design of electric motors.
- ✓ Three is the lowest phase order to exhibit all of these properties.

Most household loads are single-phase. In North America and a few other places, three-phase power generally does not enter homes. Even in areas where it does, it is typically split out at the main distribution board and the individual loads are fed from a single phase. Sometimes it is used to power electric stoves and electric clothes dryers.

3 Or 4 Wire

Three-phase circuits occur in two varieties: three-wire and four-wire. Both types have three energized ("hot" or "live") wires, but the 4-wire circuit also has neutral wire. The three-wire system is used when the loads on the 3 live wires will be balanced, for example in motors or heating elements with 3 identical coils. The neutral wire is used when there is a chance that the loads are not balanced. A common example of this is local distribution in Europe, where each house will be connected to just one of the live wires, but all connected to the same neutral.

The neutral carries the "imbalance" between the power carried on the 3 live wires. Hence electrical engineers work hard to make sure that the power is shared around equally, so the neutral wire carries as little power as possible and can therefore be made much smaller than the other 3.

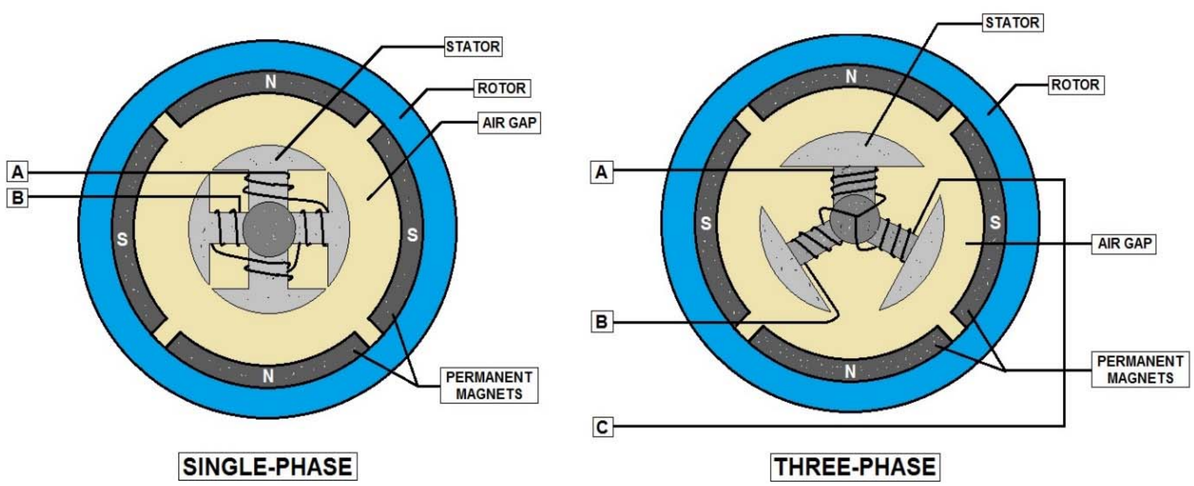
The '3-wire' and '4-wire' designations do not count the ground wire used on many transmission lines, as this is solely for fault and lightning protection and does not serve to deliver electrical power.

The most important class of three-phase load is the electric motor. A three-phase induction motor has a simple design, inherently high starting torque and high efficiency. Such motors are applied in industry for pumps, fans, blowers, compressors, conveyor drives, electric vehicles and many other kinds of motor-driven equipment.

A three-phase motor is more compact and less costly than a single-phase motor of the same voltage class and rating and single-phase AC motors above 10 HP (7.5 kW) are uncommon. Three-phase motors also vibrate less and hence last longer than single-phase motors of the same power used under the same conditions.

Resistance heating loads such as electric boilers or space heating may be connected to three-phase systems. Electric lighting may also be similarly connected. These types of loads do not require the revolving magnetic field characteristic of three-phase motors but take advantage of the higher voltage and power level usually associated with three-phase distribution. Legacy single-phase fluorescent lighting systems also benefit from reduced flicker in a room if adjacent fixtures are powered from different phases.

Large rectifier systems may have three-phase inputs; the resulting DC is easier to filter (smooth) than the output of a single-phase rectifier. Such rectifiers may be used for battery charging, electrolysis processes such as aluminum production or for operation of DC motors.



SINGLE AND THREE - PHASE MOTOR COMPARISON

More on Three-Phase Electric Power

In electrical engineering, **three-phase** electric power systems have at least three conductors carrying alternating current voltages that are offset in time by one-third of the period. A three-phase system may be arranged in delta (∆) or star (Y) (also denoted as wye in some areas). A wye system allows the use of two different voltages from all three phases, such as a 230/400V system which provides 230V between the neutral (center hub) and any one of the phases, and 400V across any two phases. A delta system arrangement only provides one voltage magnitude, however it has a greater redundancy as it may continue to operate normally with one of the three supply windings offline, albeit at 57.7% of total capacity. Harmonic currents in the neutral may become very large if non-linear loads are connected.

Definitions
In a star (wye) connected topology, with rotation sequence L1 - L2 - L3, the time-varying instantaneous voltages can be calculated for each phase A,C,B respectively by:

$$V_{L1-N} = \sin(\theta) * V_P$$
$$V_{L2-N} = \sin\left(\theta - \frac{2}{3}\pi\right) * V_P = \sin\left(\theta + \frac{4}{3}\pi\right) * V_P$$
$$V_{L3-N} = \sin\left(\theta - \frac{4}{3}\pi\right) * V_P = \sin\left(\theta + \frac{2}{3}\pi\right) * V_P$$

where:

V_P is the peak voltage,
$\theta = 2\pi f t$ is the phase angle in radians
t is the time in seconds
f is the frequency in cycles per second and
voltages L1-N, L2-N and L3-N are referenced to the star connection point.

Balanced Loads
Generally, in electric power systems, the loads are distributed as evenly as is practical between the phases. It is usual practice to discuss a balanced system first and then describe the effects of unbalanced systems as deviations from the elementary case.

Constant Power Transfer
An important property of three-phase power is that the power available to a resistive load, $P = VI = \frac{1}{R}V^2$, is constant at all times.

$$P_{Li} = \frac{V_{Li}^2}{R}$$
$$P_{TOT} = \sum_i P_{Li}$$

To simplify the mathematics, we define a non-dimensionalized power for intermediate calculations, $p = \frac{1}{V_P^2} P_{TOT} R$

$$p = \sin^2\theta + \sin^2\left(\theta - \frac{2}{3}\pi\right) + \sin^2\left(\theta - \frac{4}{3}\pi\right) = \frac{3}{2}$$

Hence (substituting back):

$$P_{TOT} = \frac{3V_P^2}{2R}$$

since we have eliminated θ we can see that the total power does not vary with time. This is essential for keeping large generators and motors running smoothly. Actually, the load need not be resistive for achieving a constant instantaneous power since, as long as it is balanced or the same for all phases, it may be written as

$$Z = |Z|e^{j\varphi}$$

so that the peak current is

$$I_P = \frac{V_P}{|Z|}$$

for all phases and the instantaneous currents are

$$I_{L1} = I_P \sin\left(\theta - \varphi\right)$$
$$I_{L2} = I_P \sin\left(\theta - \frac{2}{3}\pi - \varphi\right)$$
$$I_{L3} = I_P \sin\left(\theta - \frac{4}{3}\pi - \varphi\right)$$

Now the instantaneous powers in the phases are

$$P_{L1} = V_{L1}I_{L1} = V_P I_P \sin\left(\theta\right) \sin\left(\theta - \varphi\right)$$
$$P_{L2} = V_{L2}I_{L2} = V_P I_P \sin\left(\theta - \frac{2}{3}\pi\right) \sin\left(\theta - \frac{2}{3}\pi - \varphi\right)$$
$$P_{L3} = V_{L3}I_{L3} = V_P I_P \sin\left(\theta - \frac{4}{3}\pi\right) \sin\left(\theta - \frac{4}{3}\pi - \varphi\right)$$

Using angle subtraction formulae:

$$P_{L1} = \frac{V_P I_P}{2}\left[\cos\varphi - \cos\left(2\theta - \varphi\right)\right]$$
$$P_{L2} = \frac{V_P I_P}{2}\left[\cos\varphi - \cos\left(2\theta - \frac{4}{3}\pi - \varphi\right)\right]$$
$$P_{L3} = \frac{V_P I_P}{2}\left[\cos\varphi - \cos\left(2\theta - \frac{8}{3}\pi - \varphi\right)\right]$$

which add up for a total instantaneous power

$$P_{TOT} = \frac{V_P I_P}{2}\left\{3\cos\varphi - \left[\cos\left(2\theta - \varphi\right) + \cos\left(2\theta - \frac{4}{3}\pi - \varphi\right) + \cos\left(2\theta - \frac{8}{3}\pi - \varphi\right)\right]\right\}$$

Since the three terms enclosed in square brackets are a three-phase system, they add up to zero and the total power becomes

$$P_{TOT} = \frac{3V_P I_P}{2} \cos\varphi$$

or

$$P_{TOT} = \frac{3V_P^2}{2|Z|} \cos\varphi$$

No Neutral Current

For the case of equal loads on each of three phases, no net current flows in the neutral. The neutral current is the inverted vector sum of the line currents. See Kirchhoff's circuit laws.

$$I_{L1} = \frac{V_{L1-N}}{R},\ I_{L2} = \frac{V_{L2-N}}{R},\ I_{L3} = \frac{V_{L3-N}}{R}$$

$$-I_N = I_{L1} + I_{L2} + I_{L3}$$

We define a non-dimensionalized current, $i = \frac{I_N R}{V_P}$:

$$\begin{aligned} i &= \sin\theta + \sin(\theta - \frac{2\pi}{3}) + \sin(\theta + \frac{2\pi}{3}) \\ &= \sin\theta + 2\sin\theta\cos\frac{2\pi}{3} \\ &= \sin\theta - \sin\theta \\ &= 0 \end{aligned}$$

Since we have shown that the neutral current is zero we can see that removing the neutral core will have no effect on the circuit, provided the system is balanced. Such connections are generally used only when the load on the three phases is part of the same piece of equipment (for example a three-phase motor), as otherwise switching loads and slight imbalances would cause large voltage fluctuations.

Unbalanced Systems

In practice, systems rarely have perfectly balanced loads, currents, voltages and impedances in all three phases. The analysis of unbalanced cases is greatly simplified by the use of the techniques of symmetrical components. An unbalanced system is analyzed as the superposition of three balanced systems, each with the positive, negative or zero sequence of balanced voltages.

When specifying wiring sizes in a three-phase system, we only need to know the magnitude of the phase and neutral currents. The neutral current can be determined by adding the three phase currents together as complex numbers and then converting from rectangular to polar co-ordinates. If the three phase RMS (Root Mean Square) currents are I_{L1}, $I_{L2}$and I_{L3}, the neutral RMS current is:

$$I_{L1} + I_{L2} * \cos\frac{2}{3}\pi + j * I_{L2} * \sin\frac{2}{3}\pi + I_{L3} * \cos\frac{4}{3}\pi + j * I_{L3} * \sin\frac{4}{3}\pi$$

which resolves to

$$I_{L1} - I_{L2} * 0.5 - I_{L3} * 0.5 + j * \frac{\sqrt{3}}{2} * (I_{L2} - I_{L3})$$

The polar magnitude of this is the square root of the sum of the squares of the real and imaginary parts, which reduces to

$$\sqrt{I_{L1}^2 + I_{L2}^2 + I_{L3}^2 - I_{L1} * I_{L2} - I_{L1} * I_{L3} - I_{L2} * I_{L3}}$$

Non-linear Loads

With linear loads, the neutral only carries the current due to imbalance between the phases. Devices that utilize rectifier-capacitor front end such as switch-mode power supplies, computers, office equipment and such produce third order harmonics. 3rd, current are in-phase on all the supply phases. Third harmonics add up in neutral which can cause the neutral current in a wye system to exceed the phase current.

Revolving Magnetic Field

Any polyphase system, by virtue of the time displacement of the currents in the phases, makes it possible to easily generate a magnetic field that revolves at the line frequency. Such a revolving magnetic field makes polyphase induction motors possible. Indeed, where induction motors must run on single-phase power (such as is usually distributed in homes), the motor must contain some mechanism to produce a revolving field, otherwise the motor cannot generate any stand-still torque and will not start. The field produced by a single-phase winding can provide energy to a motor already rotating, but without auxiliary mechanisms the motor will not accelerate from a stop when energized. A rotating magnetic field of steady amplitude requires that all three phase currents be equal in magnitude, and accurately displaced one-third of a cycle in phase. Unbalanced operation results in undesirable effects on motors and generators.

Conversion to other Phase Systems

Provided two voltage waveforms have at least some relative displacement on the time axis, other than a multiple of a half-cycle, any other polyphase set of voltages can be obtained by an array of passive transformers. Such arrays will evenly balance the polyphase load between the phases of the source system. For example, balanced two-phase power can be obtained from a three-phase network by using two specially constructed transformers, with taps at 50% and 86.6% of the primary voltage. This *Scott T* connection produces a true two-phase system with 90° time difference between the phases. Another example is the generation of higher-phase-order systems for large rectifier systems, to produce a smoother DC output and to reduce the harmonic currents in the supply. When three-phase is needed but only single-phase is readily available from the electricity supplier, a phase converter can be used to generate three-phase power from the single phase supply.

System Measurements

It is possible to measure the power in a three-phase system using two transducers when there is no neutral, or three transducers when there is neutral. Blondel's theorem states that the number of measurement elements required is one less than the number of current-carrying conductors.

Phase Converters

Occasionally the advantages of three-phase motors make it worthwhile to convert single-phase power to three-phase. Small customers, such as residential or farm properties, may not have access to a three-phase supply or may not want to pay for the extra cost of a three-phase service but may still wish to use three-phase equipment. Such converters may also allow the frequency to be varied (resynthesis) allowing speed control. Some railway locomotives are moving to multi-phase motors driven by such systems even though the incoming supply to a locomotive is nearly always either DC or single-phase AC.

Because single-phase power goes to zero at each moment that the voltage crosses zero but three-phase delivers power continuously, any such converter must have a way to store the necessary energy for a fraction of a second.

One method for using three-phase equipment on a single-phase supply is with a rotary phase converter, essentially a three-phase motor with special starting arrangements and power factor correction that produces balanced three-phase voltages. When properly designed, these rotary converters can allow satisfactory operation of three-phase equipment such as machine tools on a single-phase supply. In such a device, the energy storage is performed by the mechanical inertia (flywheel effect) of the rotating components. An external flywheel is sometimes found on one or both ends of the shaft.

A second method that was popular in the 1940s and 1950s was the transformer method. At that time, capacitors were more expensive than transformers, so an autotransformer was used to apply more power through fewer capacitors. This method performs well and does have supporters, even today. The usage of the name transformer method separated it from another common method, the static converter, as both methods have no moving parts, which separates them from the rotary converters.

Another method often attempted is with a device referred to as a static phase converter. This method of running three-phase equipment is commonly attempted with motor loads though it only supplies power and can cause the motor loads to run hot and in some cases overheat. This method does not work when sensitive circuitry is involved such as CNC devices or in induction and rectifier-type loads.

A three-phase generator can be driven by a single-phase motor. This motor-generator combination can provide a frequency changer function as well as phase conversion, but requires two machines with all their expense and losses. The motor-generator method can also form an uninterruptable power supply when used in conjunction with a large flywheel and a standby generator set.

Some devices are made which create an imitation three-phase from three-wire single-phase supplies. This is done by creating a third "subphase" between the two live conductors, resulting in a phase separation of 180° - 90° = 90°. Many three-phase devices can run on this configuration but at lower efficiency.

Variable-frequency drives (also known as solid-state inverters) are used to provide precise speed and torque control of three-phase motors. Some models can be powered by a single-phase supply. VFDs work by converting the supply voltage to DC and then converting the DC to a suitable three-phase source for the motor.

Digital phase converters are designed for fixed-frequency operation from a single-phase source. Similar to a variable-frequency drive, they use a microprocessor to control solid-state power switching components to maintain balanced three-phase voltages.

Alternatives to Three-Phase

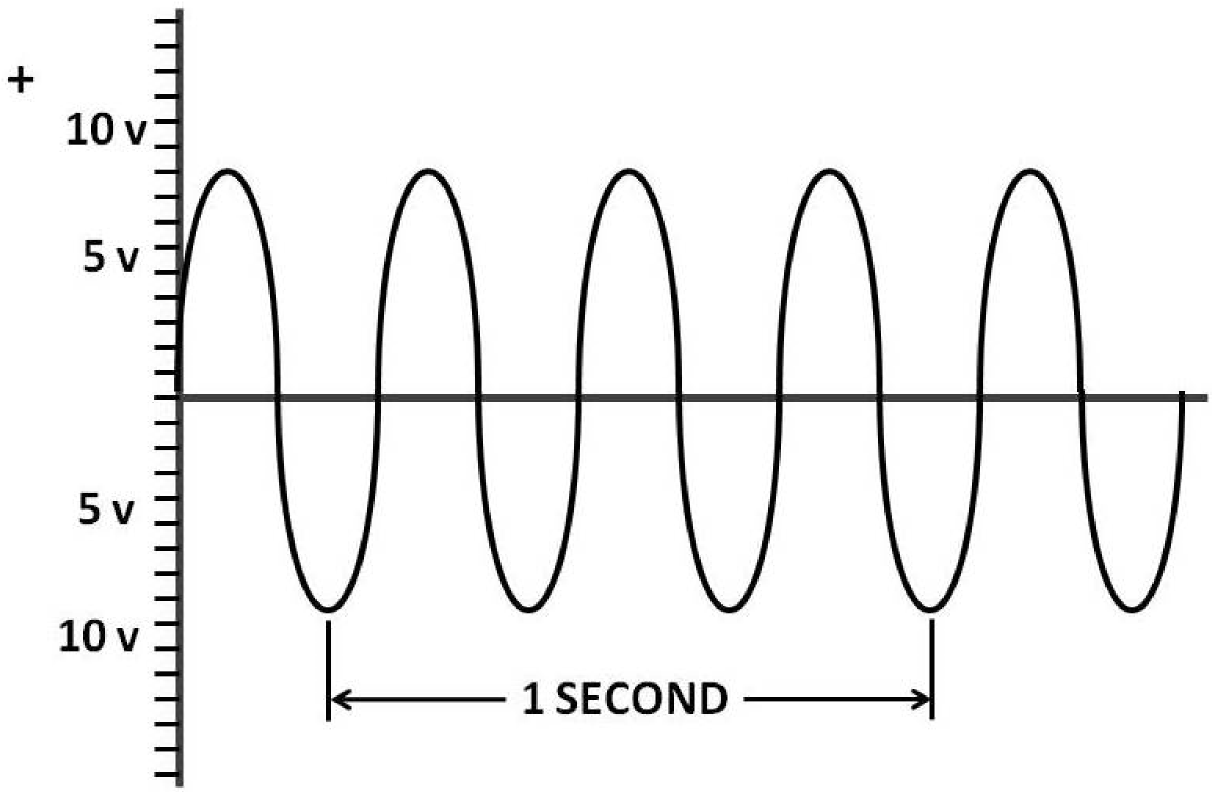
- ✓ Split-phase electric power is used when three-phase power is not available and allows double the normal utilization voltage to be supplied for high-power loads.

- ✓ Two-phase electric power, like three-phase, gives constant power transfer to a linear load. For loads that connect each phase to neutral, assuming the load is the same power draw, the two-wire system has a neutral current which is greater than neutral current in a three-phase system. Also motors are not entirely linear, which means that despite the theory, motors running on three-phase tend to run smoother than those on two-phase. The generators in the Adams Power Plant at Niagara Falls which were installed in 1895 were the largest generators in the world at the time and were two-phase machines. True two-phase power distribution is basically obsolete. Special-purpose systems may use a two-phase system for control. Two-phase power may be obtained from a three-phase system (or vice versa) using an arrangement of transformers called a Scott-T transformer.

- ✓ Monocyclic power was a name for an asymmetrical modified two-phase power system used by General Electric around 1897, championed by Charles Proteus Steinmetz and Elihu Thomson. This system was devised to avoid patent infringement. In this system, a generator was wound with a full-voltage single-phase winding intended for lighting loads and with a small fraction (usually ¼ of the line voltage) winding which produced a voltage in quadrature with the main windings. The intention was to use this "power wire" additional winding to provide starting torque for induction motors, with the main winding providing power for lighting loads. After the expiration of the Westinghouse patents on symmetrical two-phase and three-phase power distribution systems, the monocyclic system fell out of use; it was difficult to analyze and did not last long enough for satisfactory energy metering to be developed.

- ✓ High-phase-order systems for power transmission have been built and tested. Such transmission lines use six (two-pole, three-phase) or twelve (two-pole, six-phase) lines and employ design practices characteristic of extra-high-voltage transmission lines. High-phase-order transmission lines may allow transfer of more power through a given transmission line right-of-way without the expense of a high-voltage direct current (HVDC) converter at each end of the line.

AC Power Generation and Transmission



From the above sine wave graph, determine:

A. the frequency of the AC. __________

B. the peak voltage. __________

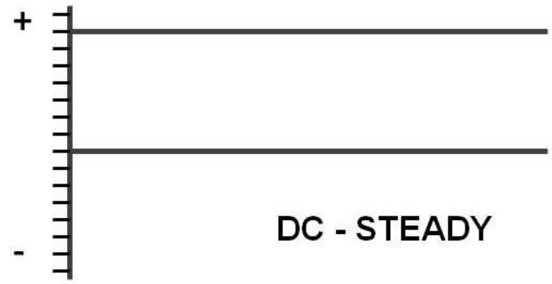
C. the RMS value of the voltage. ______________

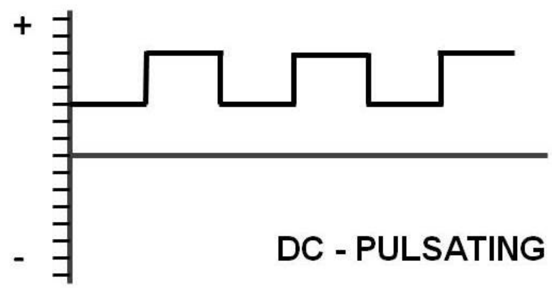
D. how long it takes the voltage to complete one cycle. __________

Direct Current versus Alternating Current

Direct current flows in one direction only. On a graph or an oscilloscope screen it always appears on one side of the zero axis, because its polarity does not change.

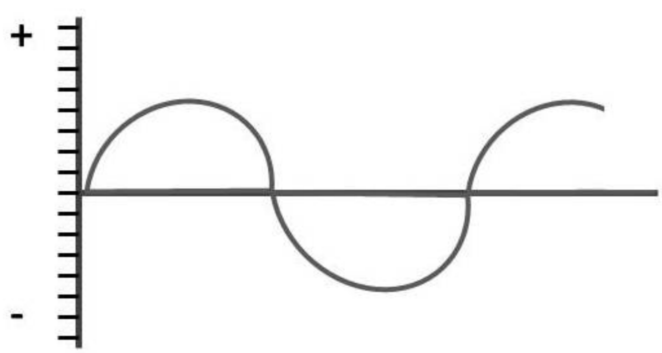
Direct current which does not change in magnitude (or current level) is called steady DC. Batteries produce steady DC.





Pulsating DC does change in magnitude. But it also always appears on the same side of the zero axis on an oscilloscope, because its polarity is constant.

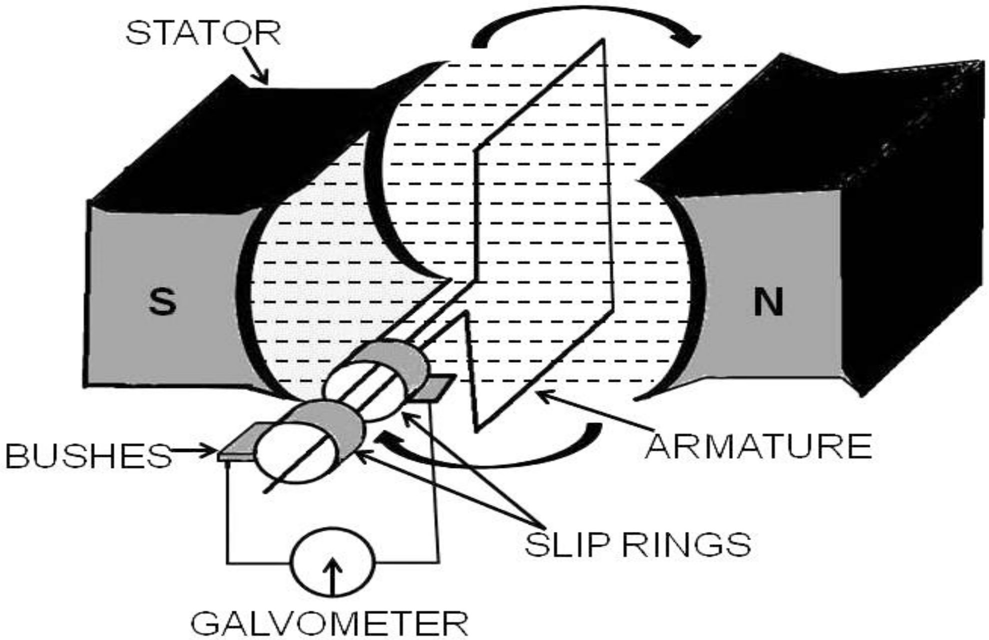
Alternating current changes in both magnitude and direction. On an oscilloscope the voltage and current appear on both sides of the zero axis, as the polarity of the voltage alternates and the current changes direction.



AC

This cycle of increase, decrease and reversal occurs on a regular basis.

Electromagnet Induction



PRODUCTION OF AC CURRENT

Alternating current is generated through an electrical effect called Electromagnet Induction**.**

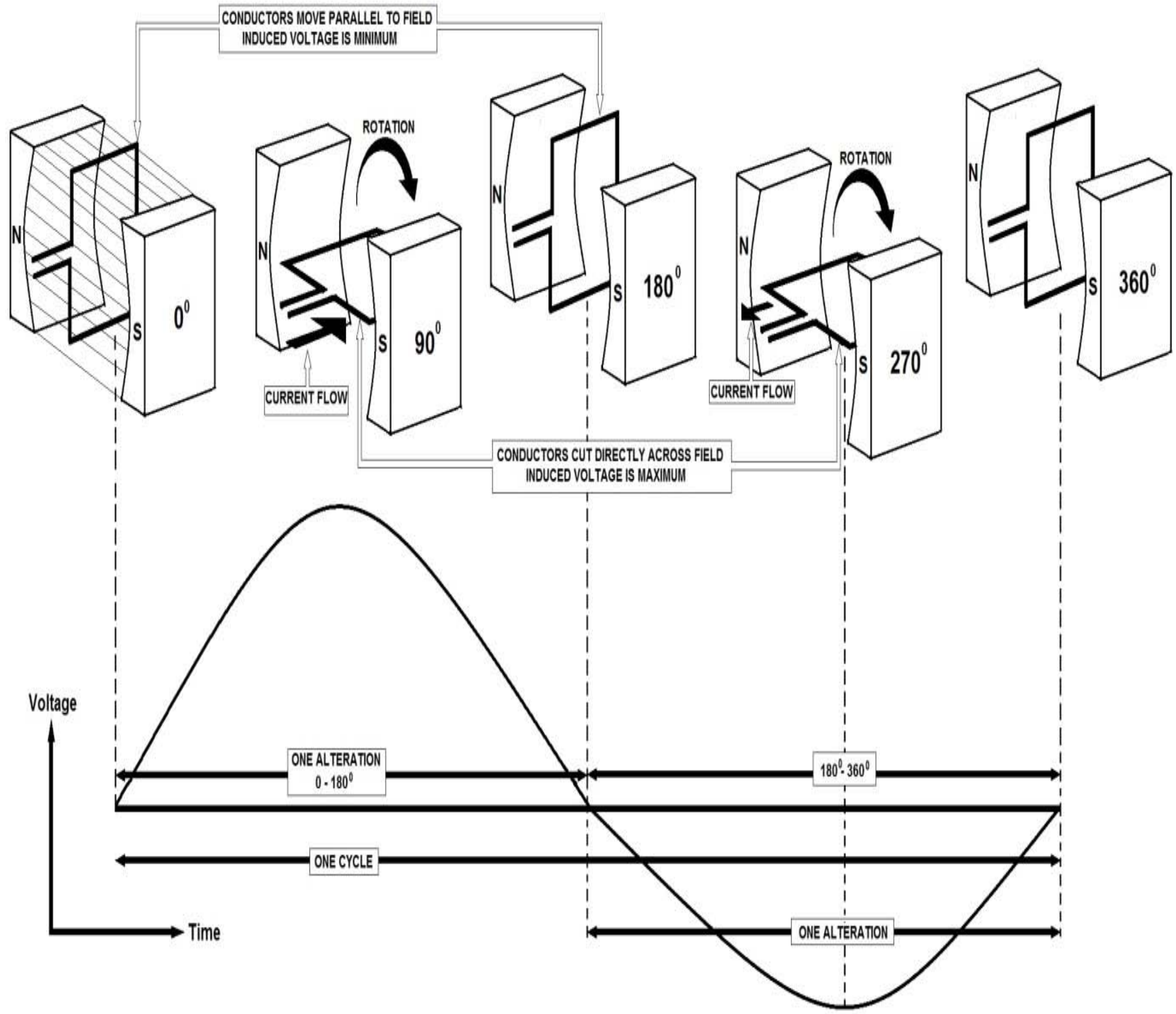
Electromagnetic Induction is the ability of a magnetic field to generate a voltage or current in a conductor without physical contact.

When the conductor becomes part of a circuit, current flows in the circuit.

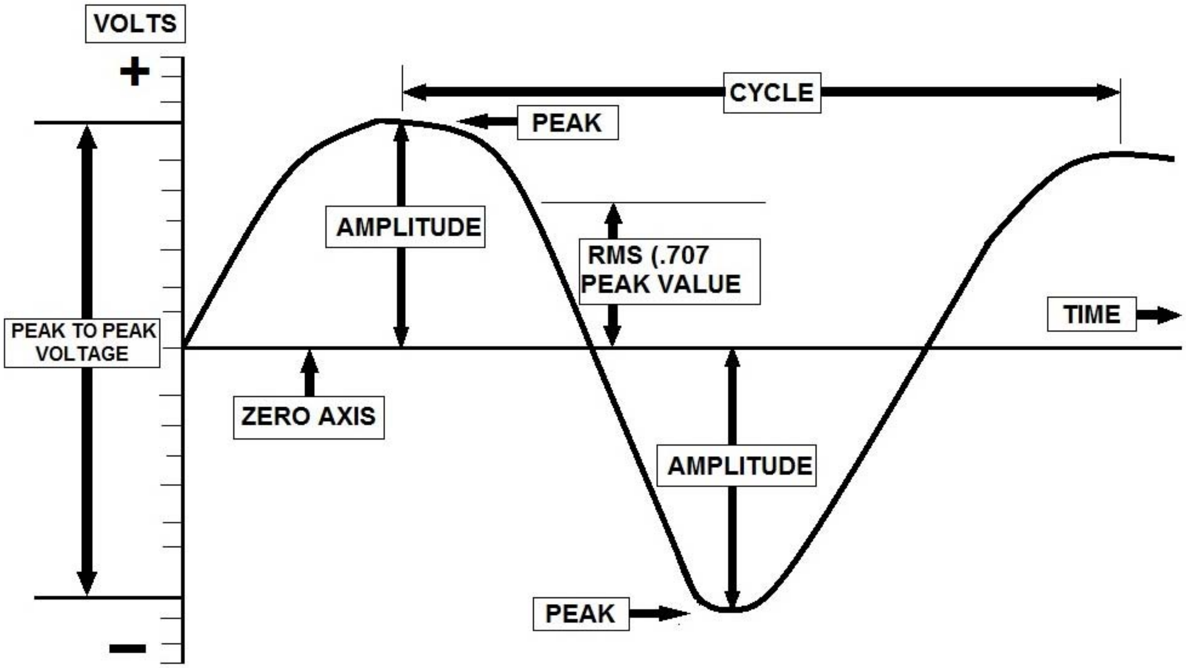
Generators convert rotational motion into current flow. As the coils are turned through a rotational magnetic, voltage is generated.

AC motors also depend upon electromagnetic induction. They convert current flow into rotational motion.

The conductor and the magnetic field are not physically connected, yet a voltage is induced in the conductor when the conductor moves through the magnetic field, or when the magnetic field moves through the conductor.


CONDUCTORS MOVE PARALLEL TO FIELD
INDUCED VOLTAGE IS MINIMUM
ROTATION
ROTATION
N
S
0°
N
S
90°
N
S
180°
N
S
270°
N
S
360°
CURRENT FLOW
CURRENT FLOW
CONDUCTORS CUT DIRECTLY ACROSS FIELD
INDUCED VOLTAGE IS MAXIMUM
Voltage
ONE ALTERATION
0 - 180°
180°- 360°
ONE CYCLE
Time
ONE ALTERATION

Sine Wave for AC



Alternating voltage and current generated by rotary motion take the form of a sine wave. It is the most common form of alternating current and voltage. As the conductor turns through the magnetic field, it cuts through the magnetic lines of force at a varying rate. As a result, voltage varies in a regular, repetitive pattern.

Sine Waves are Measured and Compared by Certain Features

1. The AMPLITUDE of the sine wave tells you the maximum value of current or voltage; it can be either positive or negative.

2. A CYCLE is one complete repetition of the wave form. It is produced by one complete revolution-360 ^{O} -of the conductor through the magnetic field. In each cycle, there are two reversals and two maximums.

The sine wave peaks in the positive direction at 90^{O} , crosses the zero axis at 180^{O}, peaks in the negative direction at 270^{O} , then reaches zero again at 360^{O} .

3. FREQUENCY is the number of cycles per second. The higher the number of cycles per second, the higher the frequency. The higher the frequency the less amount of time for one cycle. Most AC is generated at 60 cycles or 50 cycles per second.

Note: Amplitude and frequency are independent. Two waves can have the same amplitude and frequency, the same amplitude but different frequency, different amplitude but the same frequency, and different amplitude and different frequency.

4. HERTZ is the term used for cycles per (second. 60 Hertz = 60 cycles per second.

5. PEAK to PEAK voltage is the voltage measured between the maximum positive and maximum negative points on the sine wave. It is twice the amplitude.

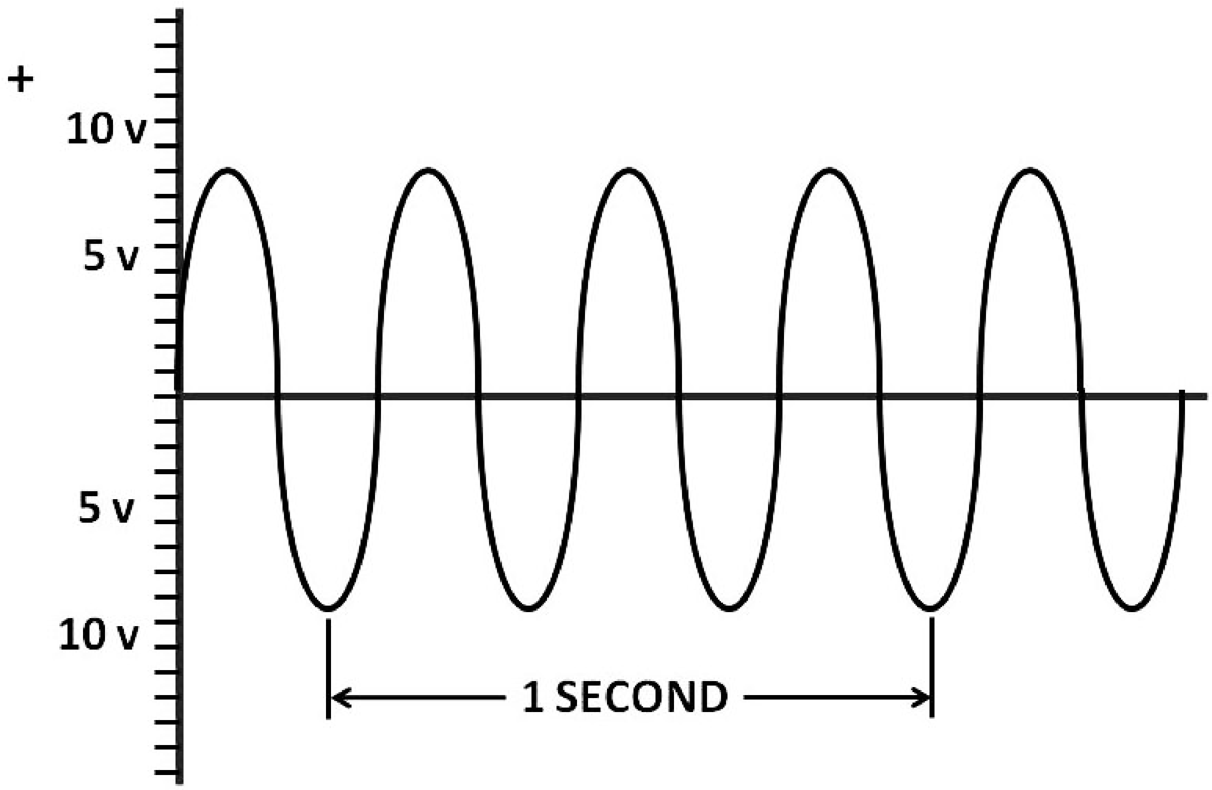
6. RMS (root mean square) voltage or current is a standard means of measuring alternating current or voltage. RMS = .707 X peak value (the amplitude of the sine wave).

7. A horizontal line through the center of the sine wave is the ZERO AXIS.

   a. All values above the zero axis are POSITIVE values; all values below the zero axis are NEGATIVE values.

   b. NEGATIVE current and voltage do just as much work as positive voltage and current. The only difference is that the polarity of the voltage is opposite and current flow is in the opposite direction. They produce exactly the same amount of power as positive current and voltage.

Practice Exercise



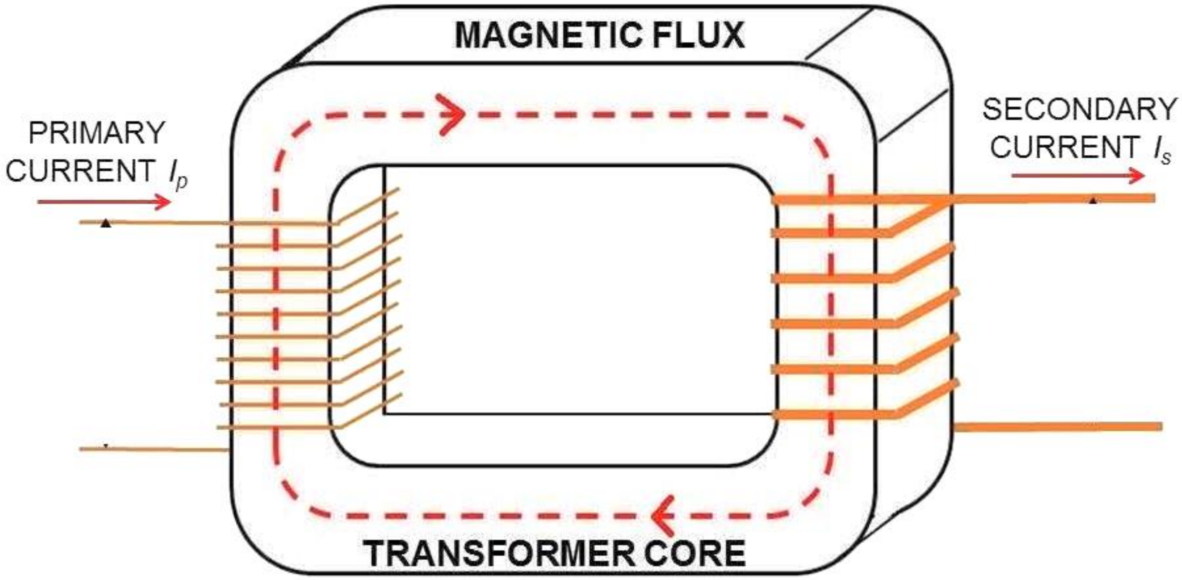
From the above sine wave graph, determine:

A. the frequency of the AC. ______

B. the peak voltage. ______

C. the RMS value of the voltage. ______

D. how long it takes the voltage to complete one cycle. ______



Practice Exercise

Section 8– Power Phases Post Quiz

1. Which term is used when loads are mostly lighting and heating, with few large electric motors?

2. Which term connected to an alternating current electric motor does not produce a revolving magnetic field?

3. Which term refers to the distribution of alternating current electric power using a system in which all the voltages of the supply vary in unison?

4. Which term are connected to windings around the interior of a motor stator, they produce a revolving magnetic field; such motors are self-starting?

Standard Frequencies of Single-Phase Power

5. High power systems, say, hundreds of kVA or larger, are nearly always?

6. Which term electric power is a common method of alternating-current electric power generation, transmission, and distribution?

7. Which term more economical than others because it uses less conductor material to transmit electric power than equivalent single-phase or two-phase systems at the same voltage?

8. Which term has the effect of giving constant power transfer over each cycle of the current and also makes it possible to produce a rotating magnetic field in an electric motor?

9. Power transfer into a _____________ is constant, which helps to reduce generator and motor vibrations.

10. Which term can produce a magnetic field that rotates in a specified direction, which simplifies the design of electric motors?

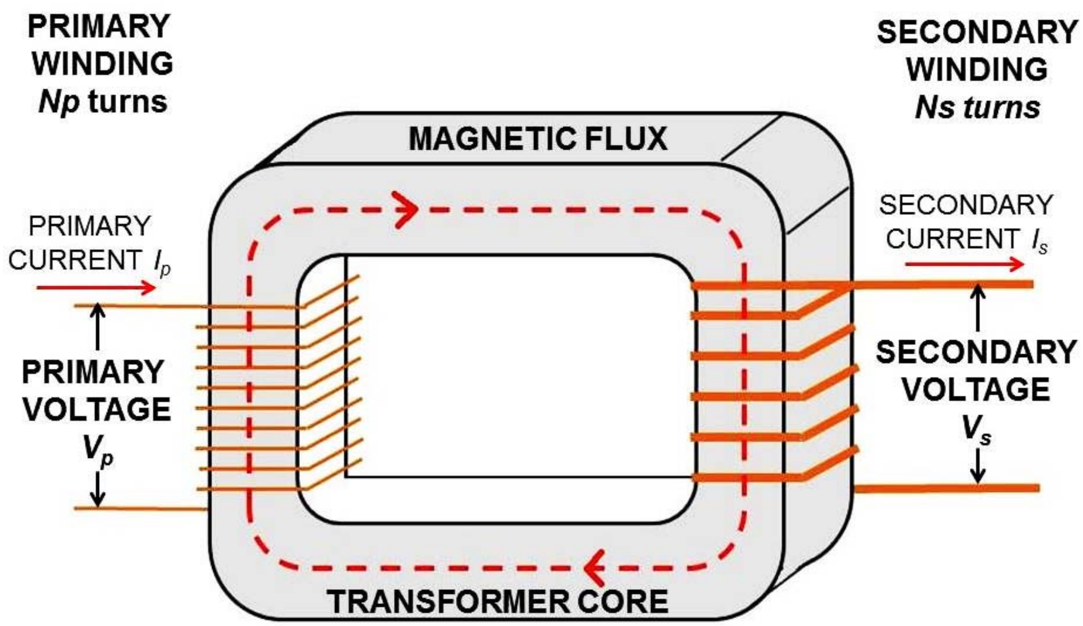
Section 8– Power Phases Post Quiz Answers

1. Single-phase distribution
2. A single-phase supply
3. Single-phase electric power
4. Three phase(s)
5. Three-phase
6. Three phase(s)
7. Three-phase system
8. This delay between phases
9. Linear balanced load
10. Three-phase systems

Section 9 – Transformers Section

Section Focus: You will learn advanced electrical theories and laws. At the end of this section, you will be able to understand and describe transformers and their purposes. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: In order to understand electrical principles, we first need to explain the various simple forms of electrical currents. Because this area of study is quite large and detailed, we will only focus on power transformers.



TRANSFORMER

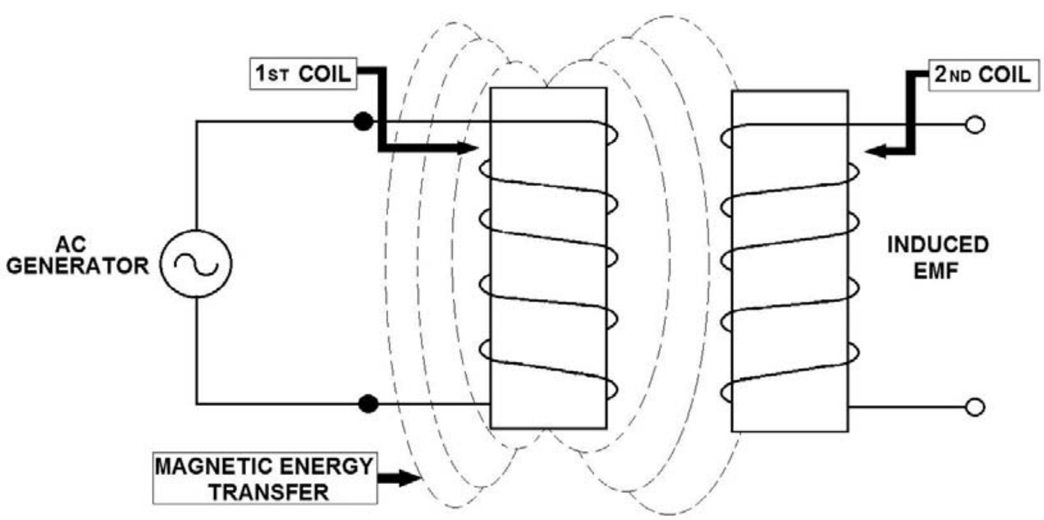
A **transformer** is an electrical device that transfers energy between two circuits through electromagnetic induction. Transformers may be used in voltage conversion to transform an AC voltage from one voltage level on the input of the device to another level at the output terminals, to provide for different requirements of current level as an alternating current source, or it may be used for impedance matching between mismatched electrical circuits to effect maximum power transfer between the circuits.

Transformers are used to increase voltage before transmitting electrical energy over long distances through wires. Wires have resistance which loses energy through joule heating at a rate corresponding to square of the current. By transforming power to a higher voltage transformers enable economical transmission of power and distribution.

Consequently, transformers have shaped the electricity supply industry, permitting generation to be located remotely from points of demand. All but a tiny fraction of the world's electrical power has passed through a series of transformers by the time it reaches the consumer.

Transformers are also used extensively in electronic products to step-down the supply voltage to a level suitable for the low voltage circuits they contain. The transformer also electrically isolates the end user from contact with the supply voltage.

Signal and audio transformers are used to couple stages of amplifiers and to match devices such as microphones and record players to the input of amplifiers. Audio transformers allowed telephone circuits to carry on a two-way conversation over a single pair of wires. A balun transformer converts a signal that is referenced to ground to a signal that has balanced voltages to ground, such as between external cables and internal circuits.



TRANSFORMER

A transformer most commonly consists of two windings of wire wound around a common core to effect tight electromagnetic coupling between the windings. The core material is often a laminated iron core. The coil that receives the electrical input energy is referred to as the primary winding, while the output coil is called the secondary winding.

An alternating electric current flowing through the primary winding (coil) of a transformer generates an electromagnetic field in its surroundings and a varying magnetic flux in the core of the transformer.

By electromagnetic induction this magnetic flux generates a varying electromotive force in the secondary winding, resulting in a voltage across the output terminals. If a load impedance is connected across the secondary winding, a current flows through the secondary winding drawing power from the primary winding and its power source.

A transformer cannot operate with direct current, but produces a short output pulse as the voltage rises when connected to the DC source.

Transformer Classification Parameters

Transformers can be classified in many ways, such as the following:

- *Power capacity*: From a fraction of a volt-ampere (VA) to over a thousand MVA.
- *Duty of a transformer*: Continuous, short-time, intermittent, periodic, varying.
- *Frequency range*: Power-frequency, audio-frequency, or radio-frequency.
- *Voltage class*: From a few volts to hundreds of kilovolts.
- *Cooling type*: Dry and liquid-immersed - self-cooled, forced air-cooled; liquid-immersed - forced oil-cooled, water-cooled.
- *Circuit application*: Such as power supply, impedance matching, output voltage and current stabilizer or circuit isolation.
- *Utilization*: Pulse, power, distribution, rectifier, arc furnace, amplifier output, etc..
- *Basic magnetic form*: Core form, shell form.
- *Constant-potential transformer descriptor*: Step-up, step-down, isolation.
- *General winding configuration*: By EIC vector group - various possible two-winding combinations of the phase designations delta, wye or star, and zigzag or interconnected star; other - autotransformer, Scott-T, zigzag grounding transformer winding.
- *Rectifier phase-shift winding configuration*: 2-winding, 6-pulse; 3-winding, 12-pulse; . . . n-winding, [n-1]*6-pulse; polygon; etc..

Transformer Types

Various specific electrical application designs require a variety of transformer types. Although they all share the basic characteristic transformer principles, they are customized in construction or electrical properties for certain installation requirements or circuit conditions.

- *Autotransformer*: Transformer in which part of the winding is common to both primary and secondary circuits.
- *Capacitor voltage transformer*: Transformer in which capacitor divider is used to reduce high voltage before application to the primary winding.
- *Distribution transformer, power transformer*: International standards make a distinction in terms of distribution transformers being used to distribute energy from transmission lines and networks for local consumption and power transformers being used to transfer electric energy between the generator and distribution primary circuits.
- *Phase angle regulating transformer*: A specialized transformer used to control the flow of real power on three-phase electricity transmission networks.
- *Scott-T transformer*: Transformer used for phase transformation from three-phase to two-phase and vice versa.
- *Polyphase transformer*: Any transformer with more than one phase.
- *Grounding transformer*: Transformer used for grounding three-phase circuits to create a neutral in a three wire system, using a wye-delta transformer, or more commonly, a zigzag grounding winding.
- *Leakage transformer*: Transformer that has loosely coupled windings.
- *Resonant transformer*: Transformer that uses resonance to generate a high secondary voltage.
- *Audio transformer*: Transformer used in audio equipment.
- *Output transformer*: Transformer used to match the output of a valve amplifier to its load.
- *Instrument transformer*: Potential or current transformer used to accurately and safely represent voltage, current or phase position of high voltage or high power circuits.

Transformer Applications

Transformers perform voltage conversion; isolation protection; and impedance matching. In terms of voltage conversion, transformers can step-up voltage/step-down current from generators to high-voltage transmission lines, and step-down voltage/step-up current to local distribution circuits or industrial customers.

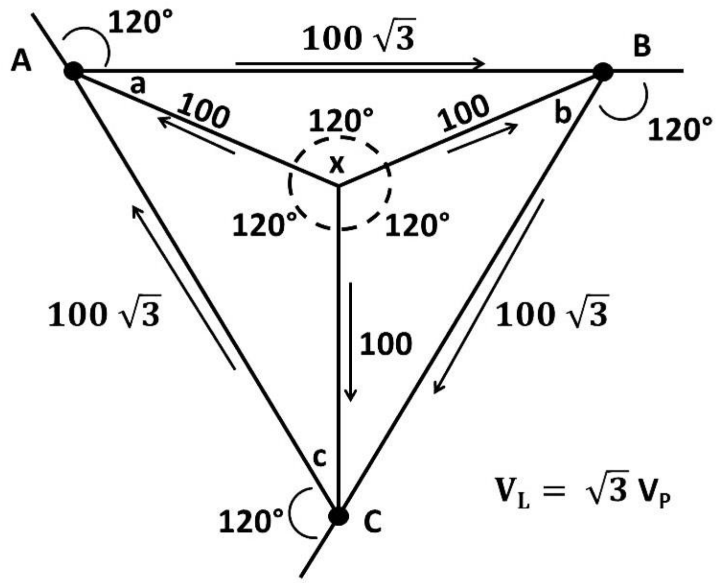
The step-up transformer is used to increase the secondary voltage relative to the primary voltage, whereas the step-down transformer is used to decrease the secondary voltage relative to the primary voltage. Transformers range in size from thumbnail-sized used in microphones to units weighing hundreds of tons interconnecting the power grid. A broad range of transformer designs are used in electronic and electric power applications, including miniature, audio, isolation, high-frequency, power conversion transformers, etc.

Transformer Basic Principles
The functioning of a transformer is based on two principles of the laws of electromagnetic induction: An electric current through a conductor, such as a wire, produces a magnetic field surrounding the wire, and a changing magnetic field in the vicinity of a wire induces a voltage across the ends of that wire.

The magnetic field excited in the primary coil gives rise to self-induction as well as mutual induction between coils.

This self-induction counters the excited field to such a degree that the resulting current through the primary winding is very small when no load draws power from the secondary winding.

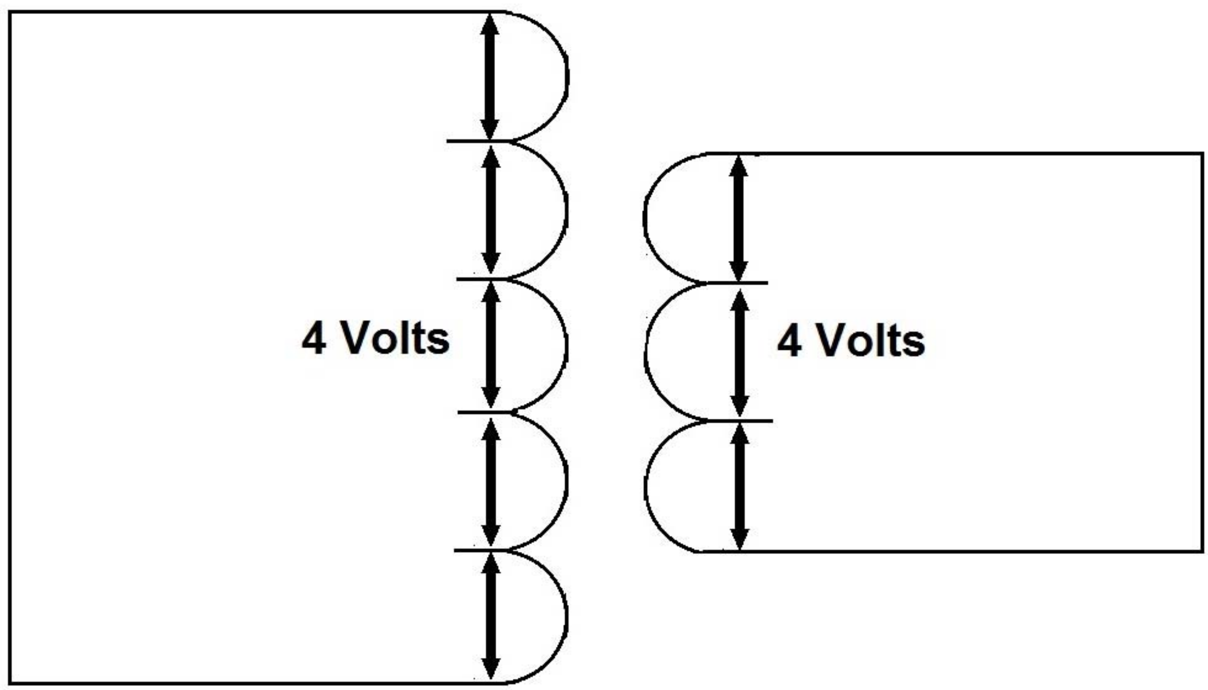
The physical principles of the inductive behavior of the transformer are most readily understood and formalized when making some assumptions to construct a simple model which is called the *ideal transformer*.



This model differs from *real transformers* by assuming that the transformer is perfectly constructed and by neglecting that electrical or magnetic losses occur in the materials used to construct the device.

Transformer Basics

- Make AC power transmission and distribution possible.
- Transform values of voltage and current.
- Operate on the principle of electromagnetic induction.
- Usually transfer AC voltages from one circuit to another.



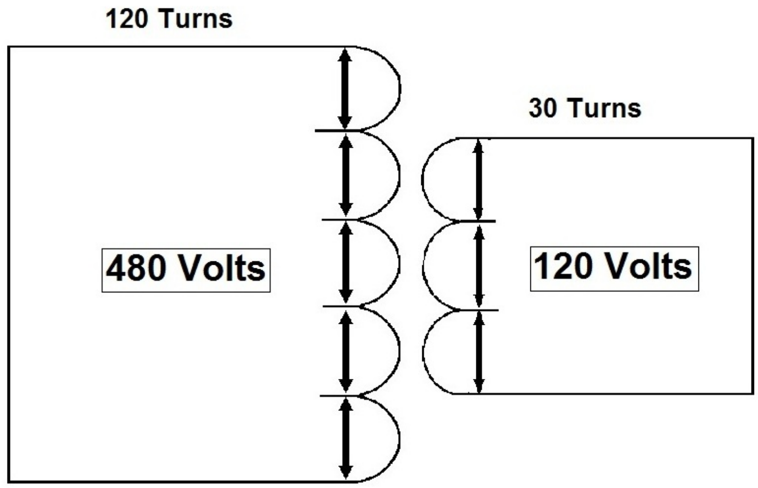
Most transformers are designed either to step voltage up or to step it down, although some are used only to isolate one voltage from another.

Transformers work because electric current generates a magnetic field around its conductor. If the current flow is steady, as in DC, the magnetic field is constant. But in AC, as the current changes direction the magnetic field keeps expanding and collapsing.

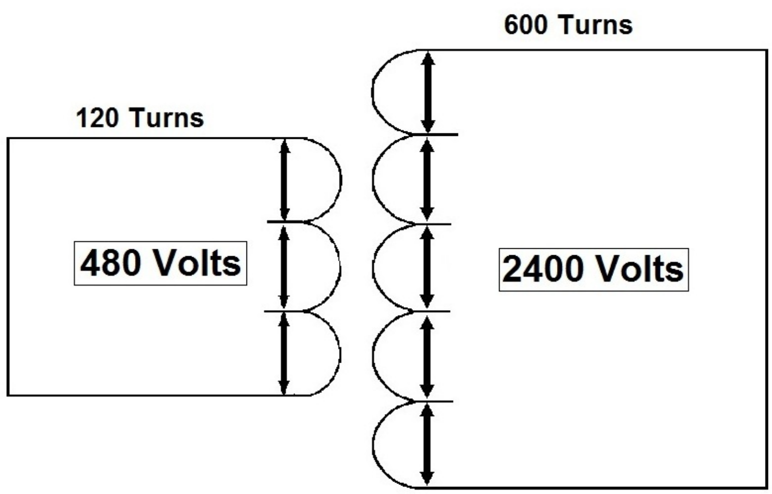
Transformers consist of a primary winding or coil connected to the source circuit and a secondary winding connected to the load circuit. When AC flows through the primary, its collapsing and expanding magnetic field induces a voltage and current in the secondary as the lines of force keep cutting through the secondary coil windings.

Each turn of wire in the, primary coil has an equal share at the primary voltage across it.

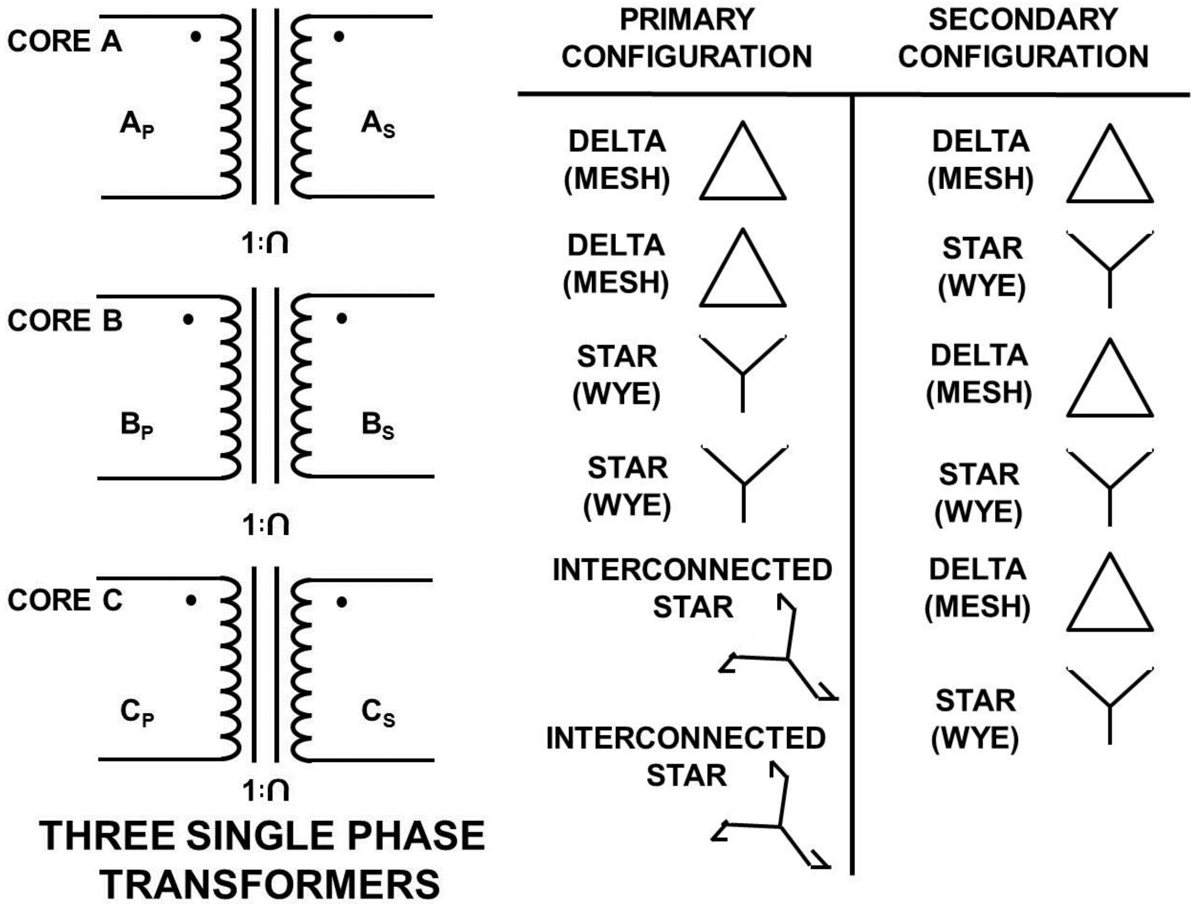
The same voltage is induced in each turn of the secondary coil. So if each turn in the primary coil has 4 volts across it, each turn in the secondary will also have 4 volts across it.



Step-Down Transformers
If there are fewer turns in the secondary, the secondary voltage will be lower than the primary.



Step-Up Transformers
If there are more turns in the secondary coil than in the primary, voltage will be higher on the secondary circuit.

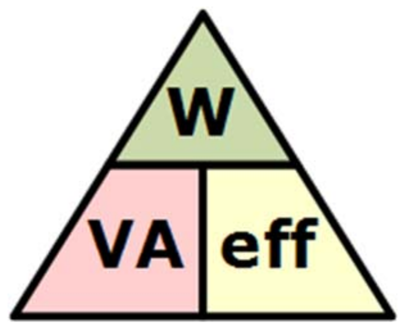


The primary and secondary windings of a transformer can be connected in different configuration as shown to meet practically any requirement. In the case of *three phase transformer* windings, three forms of connection are possible: “star” (wye), “delta” (mesh) and “interconnected-star” (zig-zag).

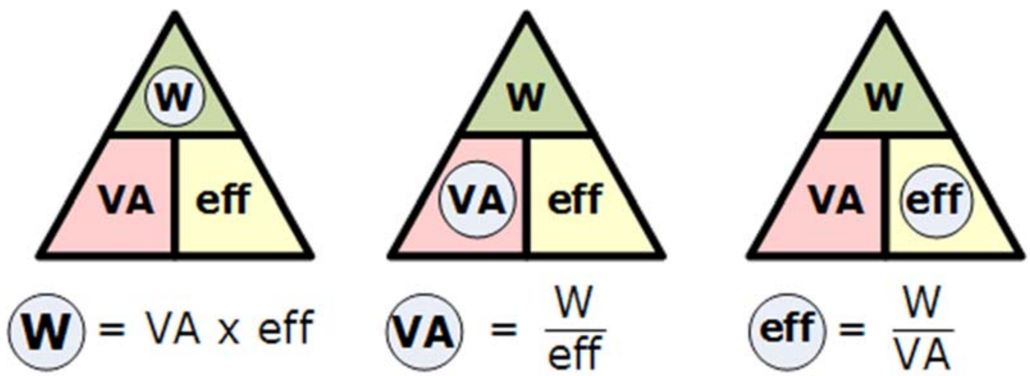
The combinations of the three windings may be with the primary delta-connected and the secondary star-connected, or star-delta, star-star or delta-delta, depending on the transformers use.

When transformers are used to provide three or more phases they are generally referred to as a **Polyphase Transformer**.

Transformer Efficiency Triangle



and transposing the above triangle quantities gives us the following combinations of the same equation:



Then, to find Watts (output) = VA x eff., or to find VA (input) = W/eff., or to find Efficiency, eff. = W/VA, etc.

Calculating Voltage

The relationship between the number of turns in the secondary and primary is called the turns ratio. This formula lets you calculate secondary voltage when you know primary voltage and the turns ratio.

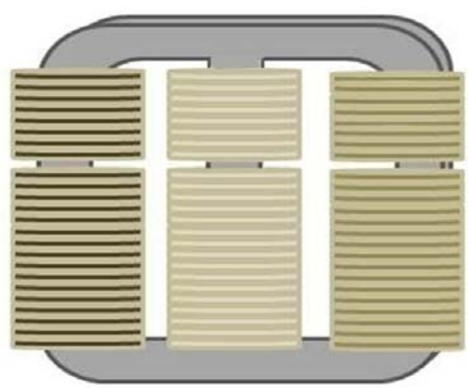
$$V_s = V_p \; x \; \frac{secondary\ turns}{primary\ turns}$$

For our step-up transformer

$$V_s = 480v \; x \; \frac{600}{120} \; or\ simplify \frac{5}{1}$$

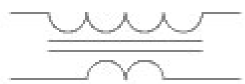
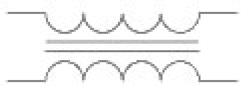
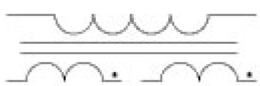
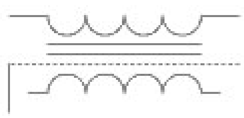
$$V_s = 480v \; x \; 5$$

$$V_s = 2400 \; v$$



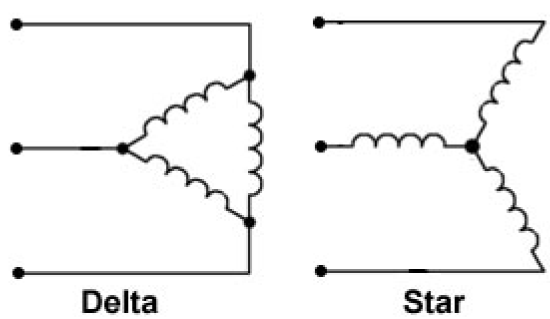
THREE PHASE TRANSFORMER

Circuit Symbols

	Two windings and an iron core, step-up or step-down as windings are different ratios.
	Transformer with two windings and an iron core.
	Transformer with three windings, two secondary windings.
	Transformer with an earth screen.

Three Phase Circuit Symbols

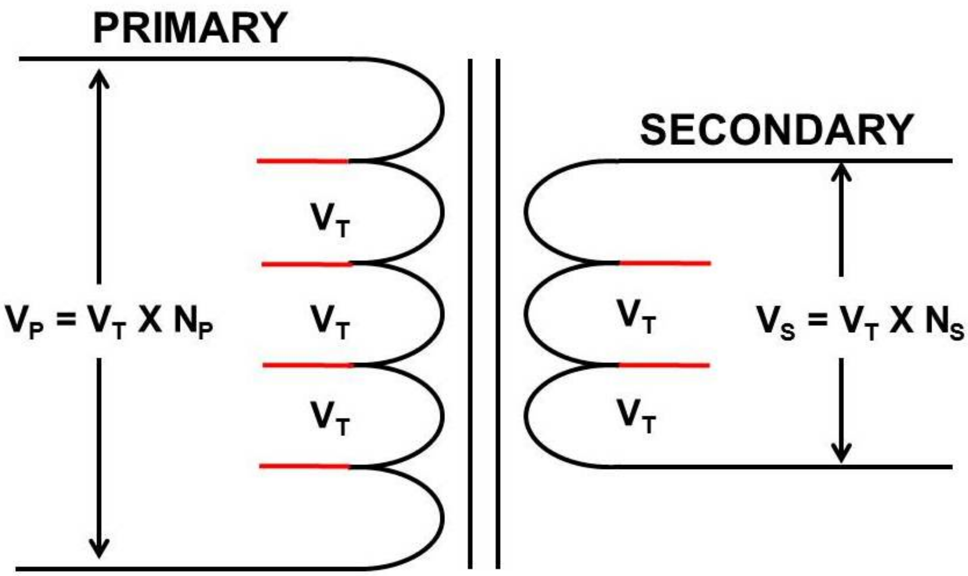
The three primary windings are connected together and the three secondary windings ar together. This is also sometimes referred to as a polyphase transformer.



The most common connections are Y-A, A-Y, A-A and Y-Y.

There are many possible configurations that may involve more or fewer than six windings and various tap connections

Connecting transformers requires knowing how to calculate voltage, current, and power.



N = number of turns in winding

The voltage across the primary will be the voltage on each tum times the number of turns. The voltage across the secondary will be the voltage on each turn times the number of turns in the secondary.

The ratio of the voltage across one winding to the voltage across the other winding is the same as the ratio of turns between windings:

The turns ratio of a transformer is often specified as the number of turns in the secondary divided by the number of turns in the primary.

$$\frac{V_S}{V_L} = \frac{T_S}{T_P} = \text{TURNS RATIO}$$

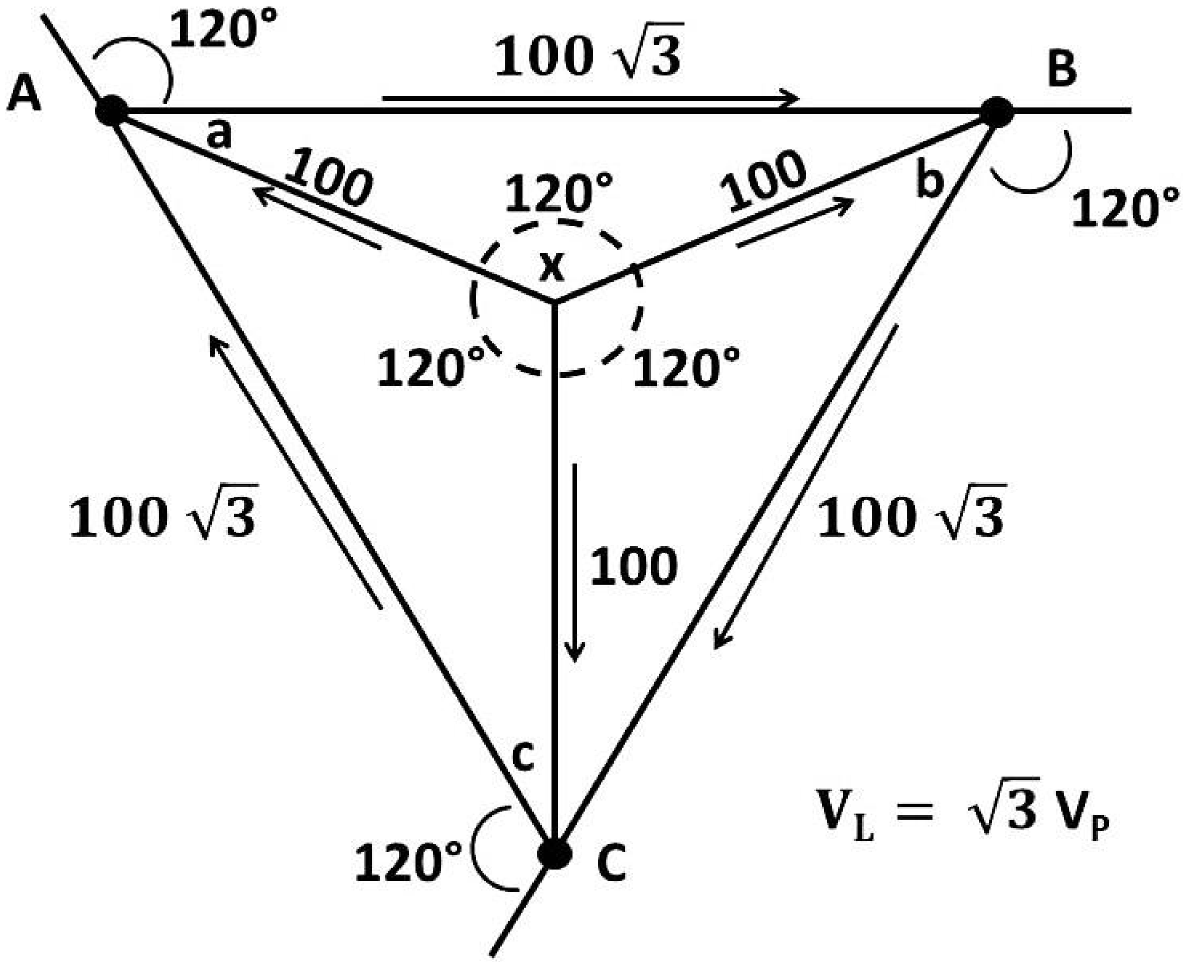
1) If the turns ratio and the primary voltage are known, the secondary voltage is simply the primary voltage times the turns ratio.

2) Secondary current, however, is primary current divided by the turns ratio.

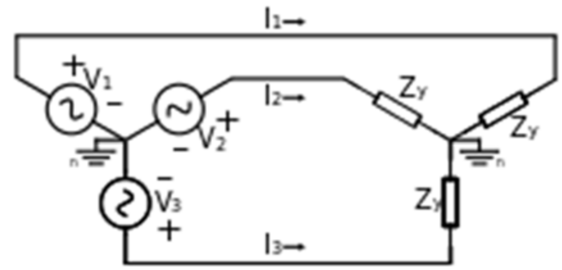
3) Transformers are usually rated in KVA (Kilovolt amperes). Current times voltage delivered to a load is very nearly equal to current times voltage into the primary, although there is some loss as heat.

When load current changes, primary current will also change. If a short develops across the load, it is almost as if the terminals of the primary winding had been shorted. A fuse or breaker on the primary side will open.

If the secondary circuit opens so that no current is being drawn, primary current will be very small.



Wye Introduction



Three phase AC generator connected as a wye source to a wye connected load.

For the wye case, all loads see their respective line voltages, and so:

$$I_1 = \frac{V_1}{|Z_{total}|}\angle(-\theta)$$

$$I_2 = \frac{V_2}{|Z_{total}|}\angle(-120^\circ - \theta)$$

$$I_3 = \frac{V_3}{|Z_{total}|}\angle(120^\circ - \theta)$$

where Z_{total} is the sum of line and load impedances ($Z_{total} = Z_{LN} + Z_Y$), and θ is the phase of the total impedance (Z_{total}).

The phase angle difference between voltage and current of each phase is not necessarily 0 and is dependent on the type of load impedance, Z_y. Inductive and capacitive loads will cause current to either lag or lead the voltage. However, the relative phase angle between each pair of lines (1 to 2, 2 to 3,and 3 to 1) will still be –120 degrees.

By performing Kirchhoff's Current Law (KCL) on the neutral node, the three phase currents sum up to the total current in the neutral line. In the balanced case:

$$I_1 + I_2 + I_3 = I_n = 0$$

Delta

In the delta circuit loads are connected across the lines and so loads see line-to-line voltages:

$$V_{12} = V_1 - V_2 = (V_{LN}\angle 0^\circ) - (V_{LN}\angle -120^\circ)$$
$$= \sqrt{3}V_{LN}\angle 30^\circ = \sqrt{3}V_1\angle(phase_{V_1} + 30^\circ)$$

$$V_{23} = V_2 - V_3 = (V_{LN}\angle -120^\circ) - (V_{LN}\angle 120^\circ)$$
$$= \sqrt{3}V_{LN}\angle -90^\circ = \sqrt{3}V_2\angle(phase_{V_2} + 30^\circ)$$

$$V_{31} = V_3 - V_1 = (V_{LN}\angle 120^\circ) - (V_{LN}\angle 0^\circ)$$
$$= \sqrt{3}V_{LN}\angle 150^\circ = \sqrt{3}V_3\angle(phase_{V_3} + 30^\circ)$$

Further:

$$I_{12} = \frac{V_{12}}{|Z_\Delta|}\angle(30^\circ - \theta)$$
$$I_{23} = \frac{V_{23}}{|Z_\Delta|}\angle(-90^\circ - \theta)$$
$$I_{31} = \frac{V_{31}}{|Z_\Delta|}\angle(150^\circ - \theta)$$

where θ is the phase of delta impedance (Z_Δ).

Relative angles are preserved, so I_{31} lags I_{23} lags I_{12} by 120 degrees. Calculating line currents by using KCL at each delta node gives:

$$I_1 = I_{12} - I_{31} = I_{12} - I_{12}\angle 120^\circ$$
$$= \sqrt{3}I_{12}\angle(phase_{I_{12}} - 30^\circ) = \sqrt{3}I_{12}\angle(-\theta)$$

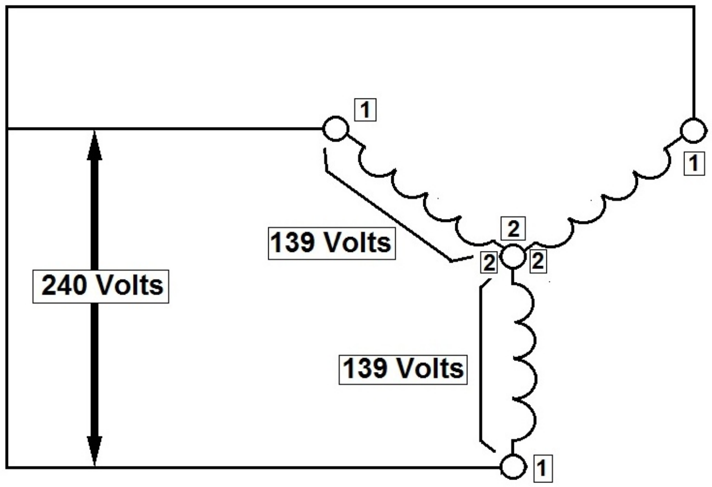
And similarly for each other line:

$$I_2 = \sqrt{3}I_{23}\angle(phase_{I_{23}} - 30^\circ) = \sqrt{3}I_{23}\angle(-120^\circ - \theta)$$

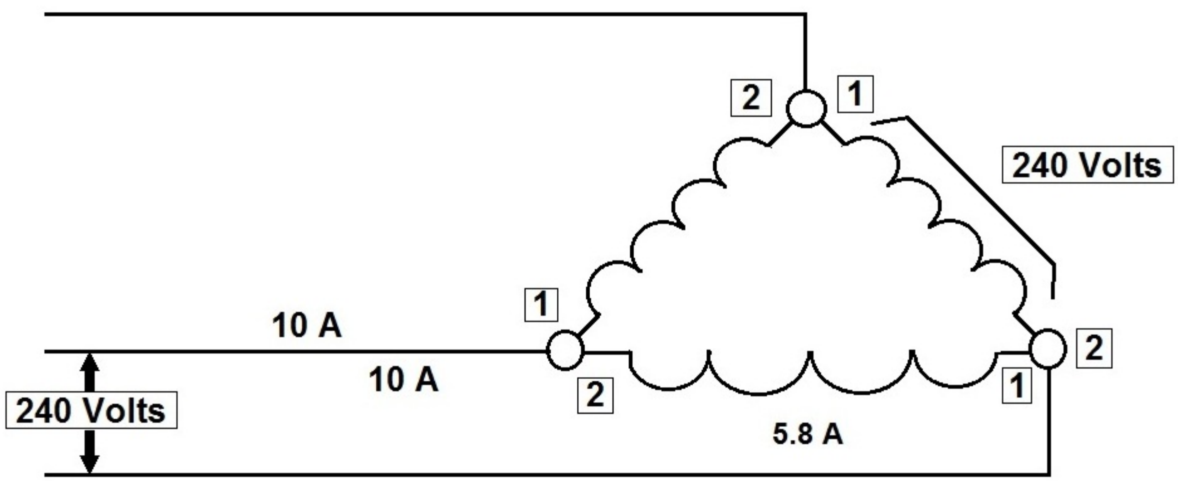
$$I_3 = \sqrt{3}I_{31}\angle(phase_{I_{31}} - 30^\circ) = \sqrt{3}I_{31}\angle(120^\circ - \theta)$$

again, θ is the phase of delta impedance (Z_Δ).

Three Phase Wyes and Deltas



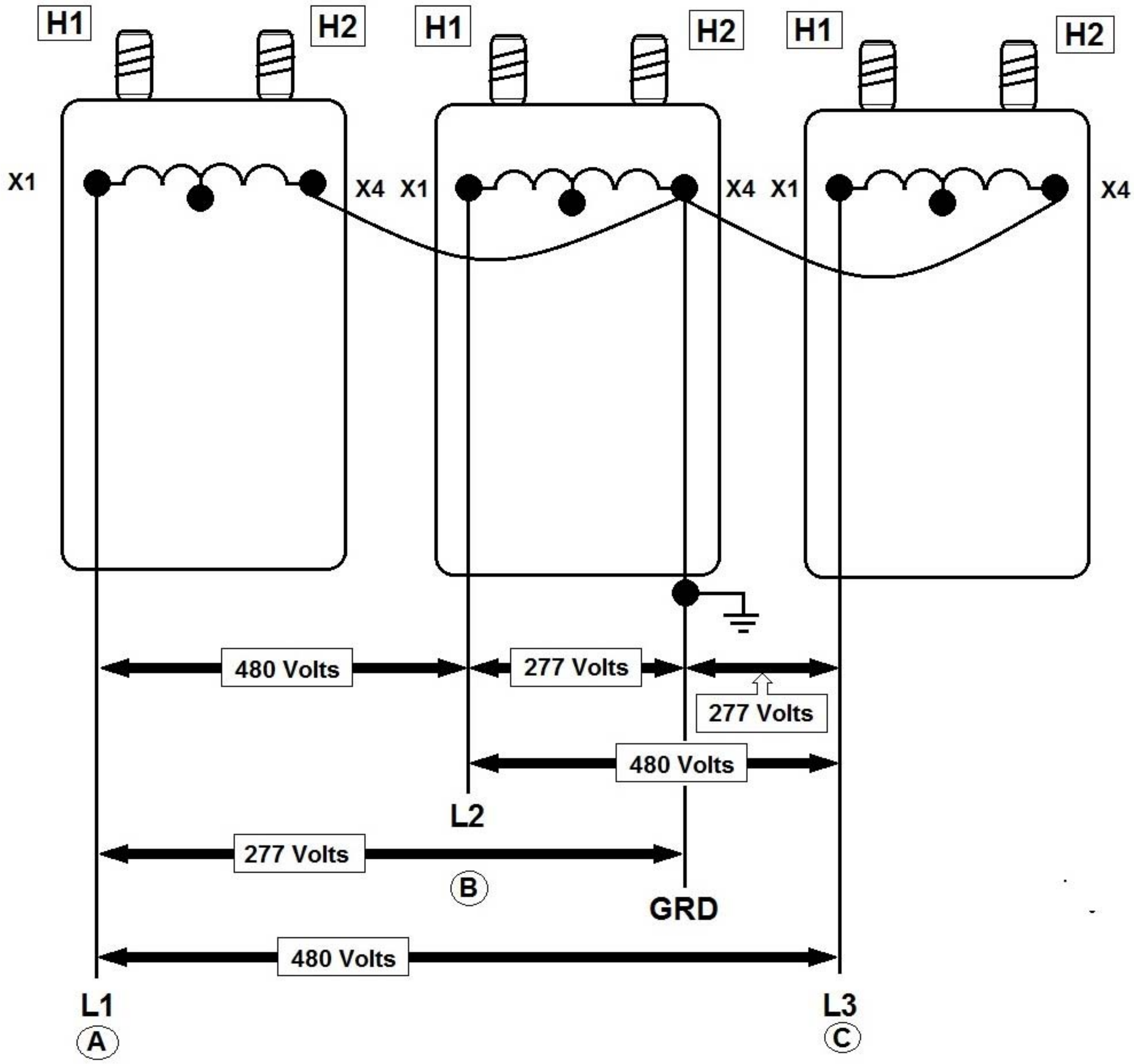
Three phase voltages can be generated and transformed as either a Wye or a Delta. Wye and Delta refer to the connections between the single phase windings which connect to create three phase voltages. Notice the polarity of each winding at the connection points. In a Wye all the ends or 2's are connected together while the beginnings or I's are connected to the three phase power source, LI, L2, and L3. In a Delta the end (2) of one winding is connected to the beginning (1) of .another winding. Three phase power is connected to each of these 1,2 junction points.



Each system, Wye and Delta, has a useful purpose. Voltage flow affects each system. differently due to polarity and the physical relationship of each winding to another.

In a Wye system voltage phase to phase is 1.73 times greater than the phase-to-ground voltage.

The 1.73 is derived from the square root of three. This accounts for the relationship of the three different single phase voltages. In a Delta system the phase-to-phase current is 1.73 times greater than the current in each individual phase or winding.



The Wye system is quite popular for newer and larger commercial and industrial buildings.

Wye systems must always be grounded to stabilize the voltage levels. 480 Volts is one of the best voltages to operate three phase motors. 277 Volts is one of the best voltages to operate High Intensity Discharge lighting. A Wye system can deliver both of these voltages. Phase-to-phase the voltage is 480. Phase-to-ground the voltage is 277.

For any three phase system to operate efficiently the single phase loads must be balanced.

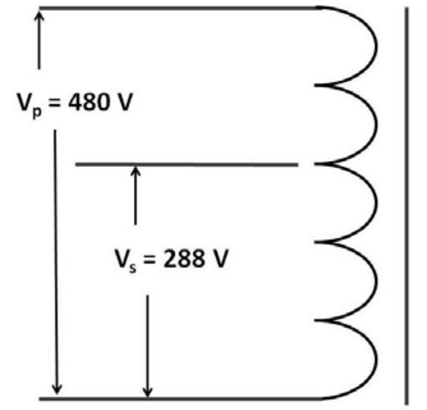
The current delivered on Phase A should equal the current delivered on Phase B.

The current delivered on Phase B should equal the current delivered on Phase C.

Of course no system will be perfectly balanced due to varying single phase loads. However, the goal is to balance the loads as close as possible.

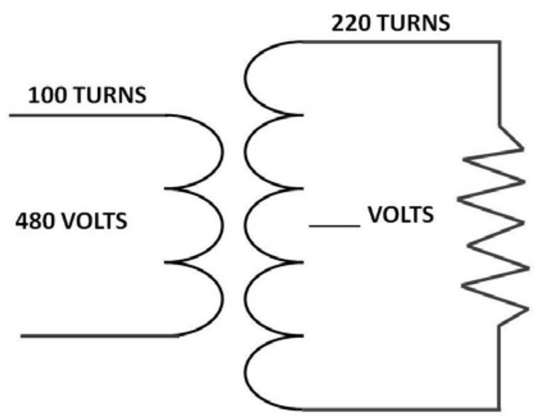
Autotransformers

Most transformers have primary and secondary coils which are insulated from each other. In Autotransformers, however, the primary and secondary share a common winding.

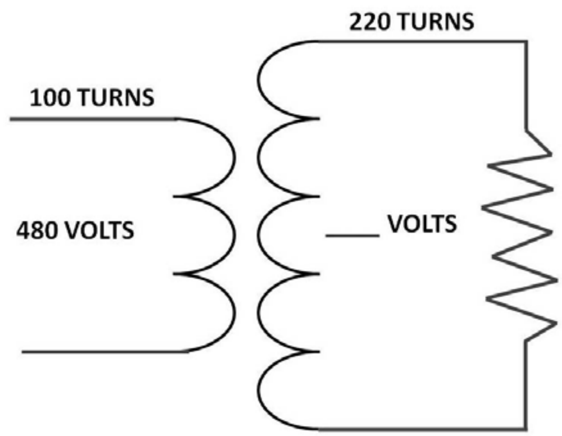


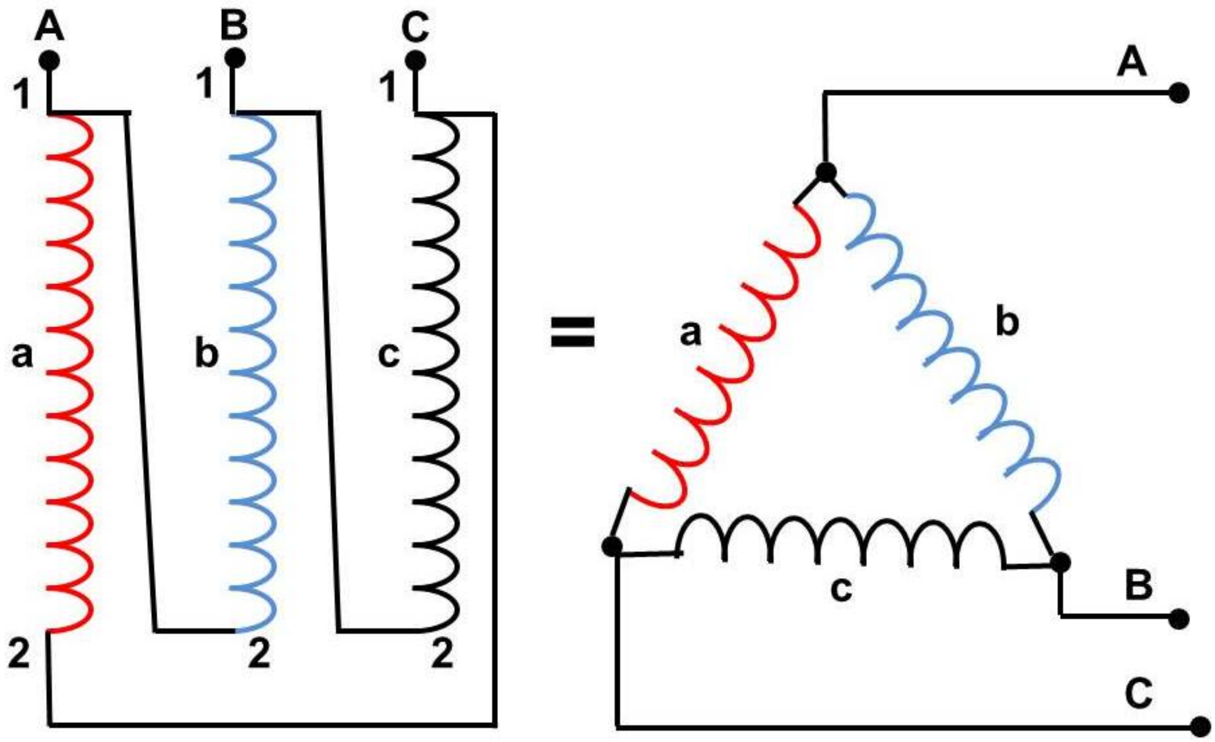
- The part of the winding connected to the source is the primary winding.
- The part of the winding connected to the load is the secondary winding.
- The winding can be tapped at any point to form either the primary or the secondary portion of the winding.
- The location of the tap determines the number of turns in the primary or secondary windings.

Practice Exercise
(a) Is this a step-up or step-down transformer?
(b) What is the voltage in the secondary?



(a) What is the voltage across the 220-turn secondary?
(b) What is the voltage per turn in the secondary?
(c) If the load is 100 ohms, what is the current on the secondary side of the transformer?





DELTA CONNECTION

Power Through a Transformer

Transformers are very efficient. The power output of the secondary is almost the same as the power the source puts into the primary.

$$P_s = P_p$$

Since power equals current times voltage, secondary current x. secondary voltage = primary current x primary voltage.

$$I_s V_s = I_p V_p$$

This means that as voltage is stepped-up or stepped-down on the secondary, current changes in the opposite direction.

If the voltage is stepped-down, current must increase.

$$I_s V_s = I_p V_p$$

100 amps x 600 volts = 20 amps x 3000 volts

Line Loss
Transformers are essential for transmitting power efficiently. Whenever power is sent over transmission lines, the resistance of the lines results in power lost in the form of heat. The formula for power loss - shows what a great effect current level has on power loss.

$$P=I^2R$$

Line losses can be reduced tremendously by lowering current. At the generating station step-up transformers are used to raise voltage to extremely high levels, sometimes more than 100,000 volts. Current becomes low, and line losses are held to a minimum.

At substations and service drops, step-down transformers reverse the process, lowering the voltage back to usable levels.

Polyphase System

A **polyphase system** is a means of distributing alternating-current electrical power. Polyphase systems have three or more energized electrical conductors carrying alternating currents with a definite time offset between the voltage waves in each conductor. Polyphase systems are particularly useful for transmitting power to electric motors.

The most common example is the three-phase power system used for industrial applications and for power transmission. The most obvious advantage of three-phase power transmission using three wires, as compared to single-phase power transmission over two wires, is that the power transmitted in the three-phase system is the voltage multiplied by the current in each wire times the square root of three (approximately 1.73). The power transmitted by the single-phase system is simply the voltage multiplied by the current. Thus the three-phase system transmits 73% more power but uses only 50% more wire.

Phases
In the very early days of commercial electric power, some installations used two-phase four-wire systems for motors. The chief advantage of these was that the winding configuration was the same as for a single-phase capacitor-start motor and, by using a four-wire system, conceptually the phases were independent and easy to analyze with mathematical tools available at the time.

Two-phase systems can also be implemented using three wires (two "hot" plus a common neutral). However this introduces asymmetry; the voltage drop in the neutral makes the phases not exactly 90 degrees apart.

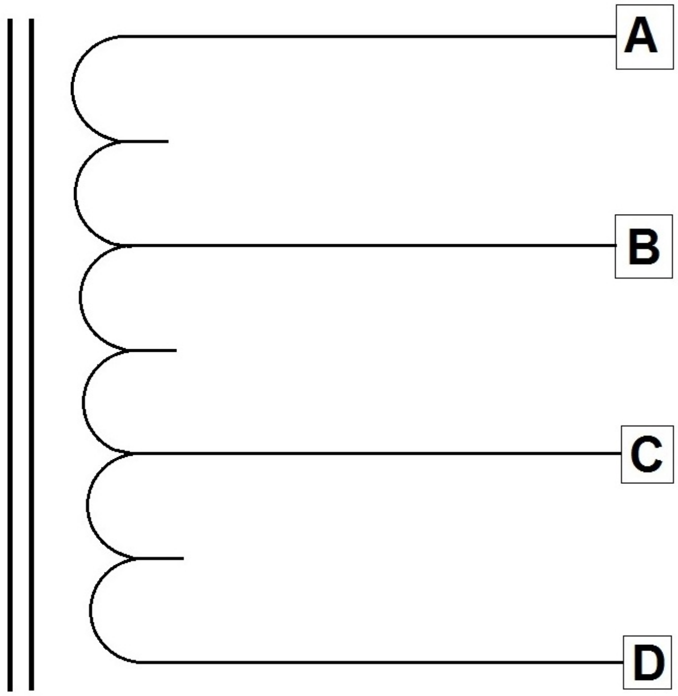
Two-phase systems have been replaced with three-phase systems. A two-phase supply with 90 degrees between phases can be derived from a three-phase system using a Scott-connected transformer.

A polyphase system must provide a defined direction of phase rotation, so mirror image voltages do not count towards the phase order. A 3-wire system with two phase conductors 180 degrees apart is still only single phase. Such systems are sometimes described as split-phase.

Motors
Polyphase power is particularly useful in AC motors, such as the induction motor, where it generates a rotating magnetic field. When a three-or-more-phase supply completes one full cycle, the magnetic field of a two-poles-per-phase motor has rotated through 360° in physical space; motors with more than two poles per phase require more power supply cycles to complete one physical revolution of the magnetic field and so these motors run slower. Induction motors using a rotating magnetic field were independently invented by Galileo Ferraris and Nikola Tesla (1885 - 1887) and developed in a three-phase form by Mikhail Dolivo-Dobrovolsky in 1889.

Previously all commercial motors were DC, with expensive commutators, high-maintenance brushes and characteristics unsuitable for operation on an alternating current network. Polyphase motors are simple to construct, are self-starting and have little vibration compared with single-phase motors.

Practice Exercise

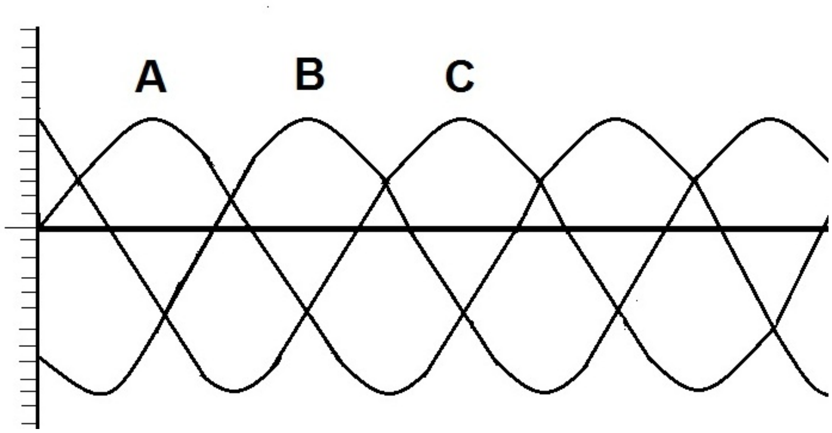


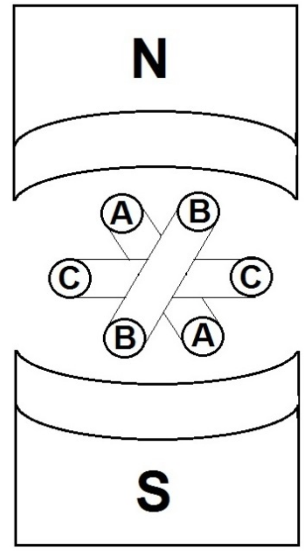
The autotransformer shown above has two taps, equally spaced on the winding. At which points should the primary and secondary connections be made to:

	Primary	Secondary
1. step 240 volts up to 480 volts.	________	__________
2. step 240 volts down to 160 volts.	________	__________
3. provide 30 amperes out with 10 amperes in.	________	__________

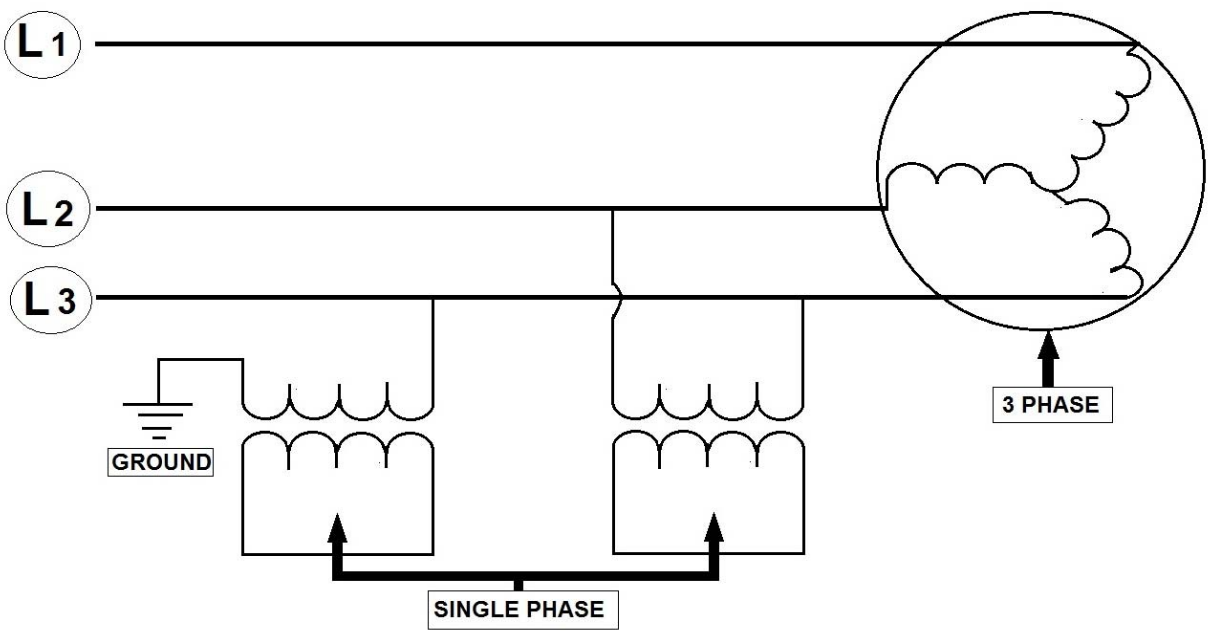
3-Phase Power

Most power is distributed in the form of 3-phase AC. Basically, instead of just one coil turning in a generator, there are three coils, spaced 120 degrees apart.

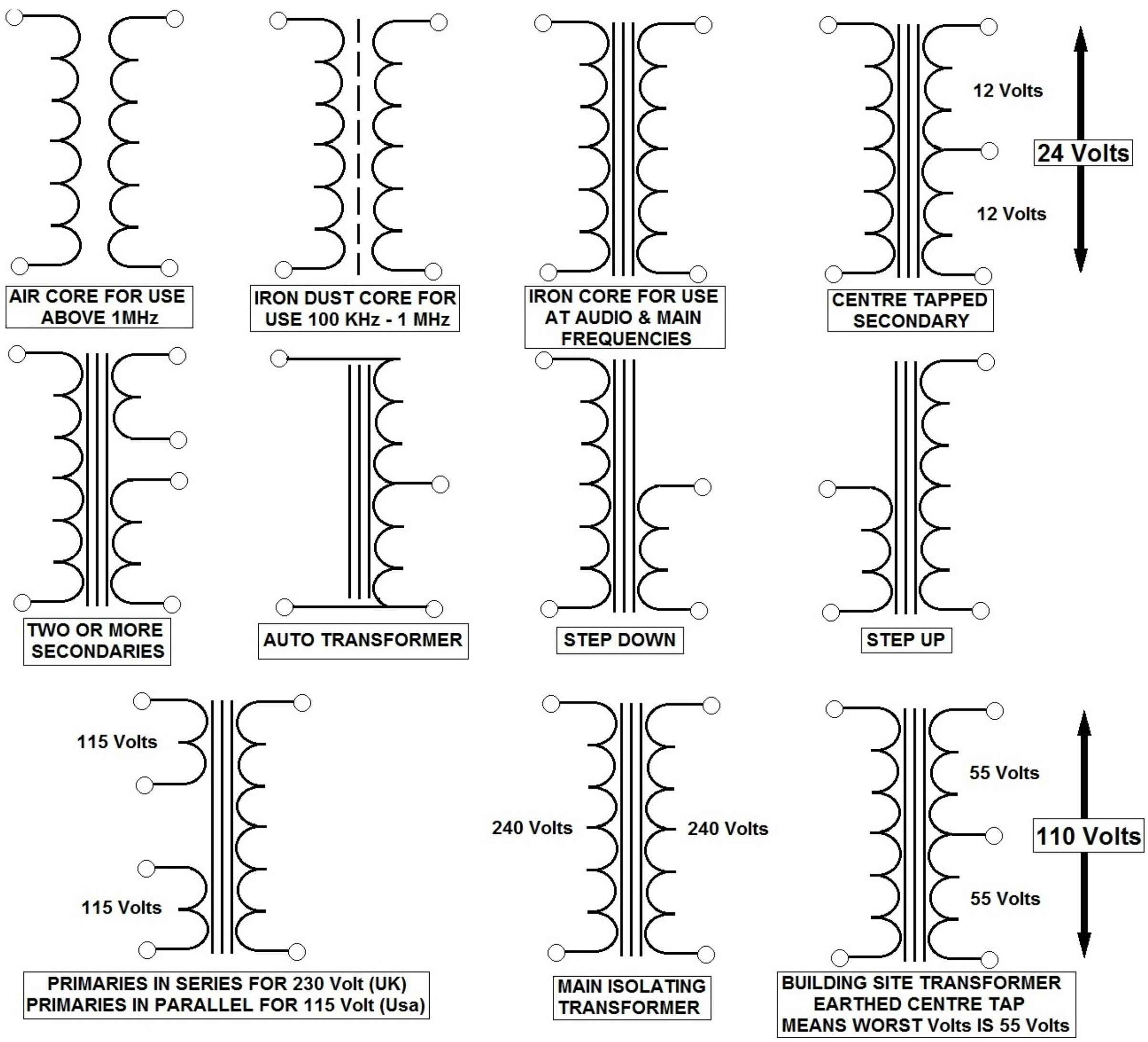




As the coils turn through the magnetic field, power is sent out on three lines. Three current and voltage sine waves are generated, 120 degrees out of phase with each other. Each sine wave represents the current or voltage on one of the phases.



Three-phase electricity powers large industrial loads more efficiently than single phase electricity. When- single-phase electricity is needed, it is available between any two phases, or, in some systems, between one of the phases and ground.

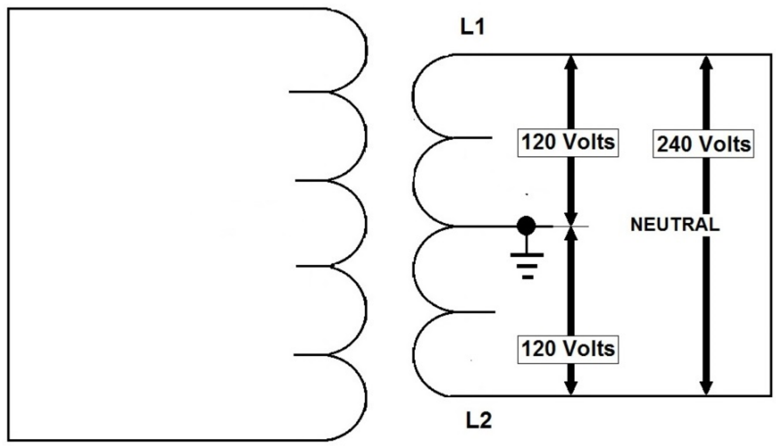


TYPES OF TRANSFORMERS

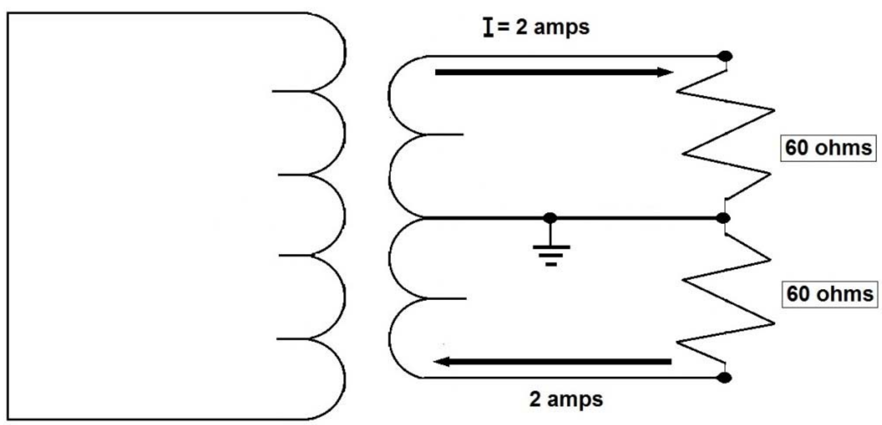
Higher Phase Order
Higher phase numbers than three have been used. A common practice for rectifier installations and in HVDC converters is to provide six phases, with 60 degree phase spacing, to reduce harmonic generation in the AC supply system and to provide smoother direct current.

Experimental high-phase-order transmission lines have been built with up to 12 phases. These allow application of Extra High Voltage (EHV) design rules at lower voltages and would permit increased power transfer in the same transmission line corridor width.

The Edison System

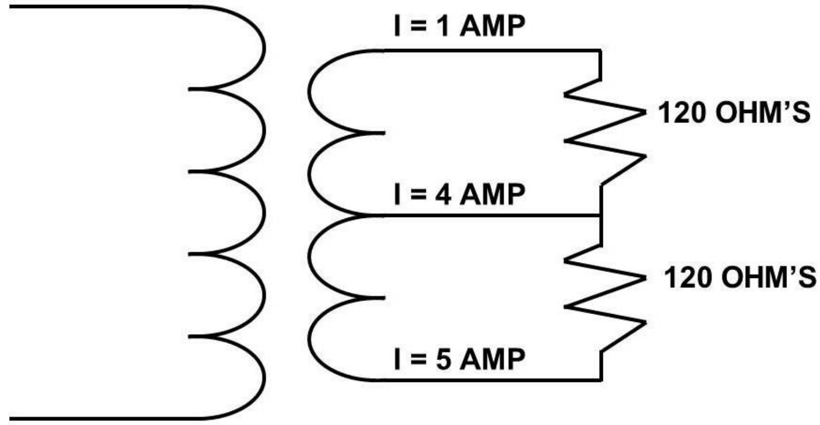


Most single-phase AC is supplied from a 3-wire EDISON SYSTEM. There are two hot conductors, and one grounded neutral conductor. In a 120/240 volt system, the voltage between each hot wire and neutral is 120 volts. Voltage between the two hot wires is 240 volts. In a 240/480 volt system, available voltages are 240 volts and 480 volts.



A main advantage of the Edison system is that full line-to-line voltage is available for large power consuming appliances and equipment, but voltage to ground is only half line-to-line voltage. The lower the voltage to ground in any electrical system, the less likely are shorts, fires, and shocks.

Balanced and Unbalanced Loads on the Edison System
When loads are balanced, that is, when they have the same resistance, the same current flows in each hot wire. But at any instant the currents in the hot wires are flowing in the opposite direction. So the current that flows through one load continues on through the other, and no current flows in the neutral.



When loads are not balanced-the resistance of one is greater than the other- current flows in the neutral. The neutral carries the difference between the current in the first load and the current in the second load.

System Groundling

Most electrical supply systems, both AC and DC, are grounded at some point as a safety measure. "Grounding" or "Earthing" means connecting something with an electrical conductor to the earth.

All conductors or metal parts-conduit, ground busses, equipment enclosures, junction boxes, machine frames-which are connected to ground at some point have zero voltage on them with respect to ground. There is no possibility of current flowing between them and anything that touches them. They cannot provide shocks.

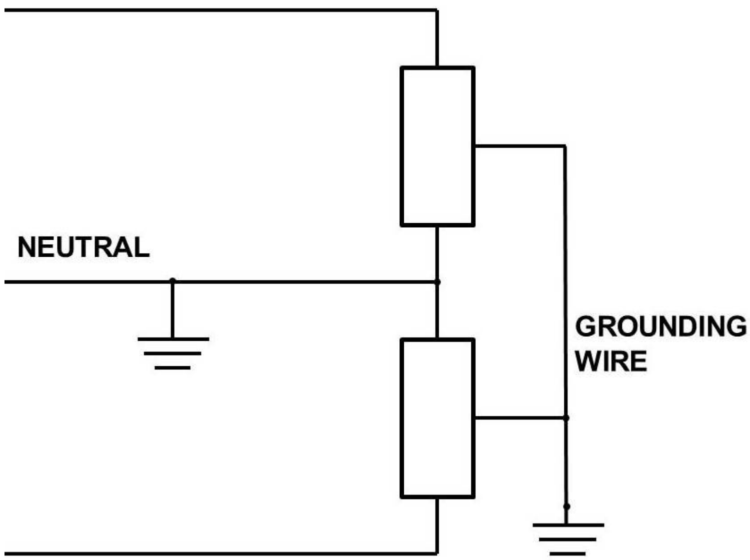
In grounded systems, insulation faults or shorts to ground on hot conductors will carry high current and blow fuses or trip breakers. This is how the system is supposed to work.

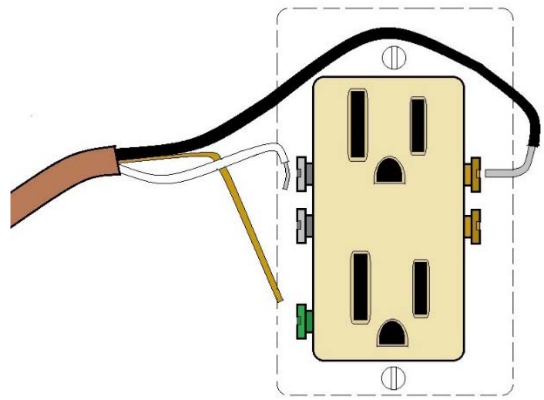
If the ground connection is broken, however, an insulation fault or short to ground on a hot conductor may not open a fuse or breaker, or affect system operation at all.

But voltage on all conductors and parts that are supposed to be grounded will rise to full system voltage-a very dangerous situation! In effect, the short to ground on the hot conductors has grounded the system there, and reversed the hot and the supposedly grounded parts of it. So it is important that all conductors and parts which are supposed to be grounded are in fact connected to ground through no resistance.

It is also important to recognize the difference between a Grounded Conductor and a Grounding Wire.

A Grounded Conductor is any conductor that is grounded at the source and carries load current.





TYPICAL COLOR CODING FOR 120 VOLT WIRING

For example, the neutral in a 3-wire Edison system is a grounded conductor, because it is normally expected to carry load current whenever the loads are unbalanced. It should not normally be used to ground parts or equipment. If resistance developed in its connections, anything connected to ground by it would have voltage on it.

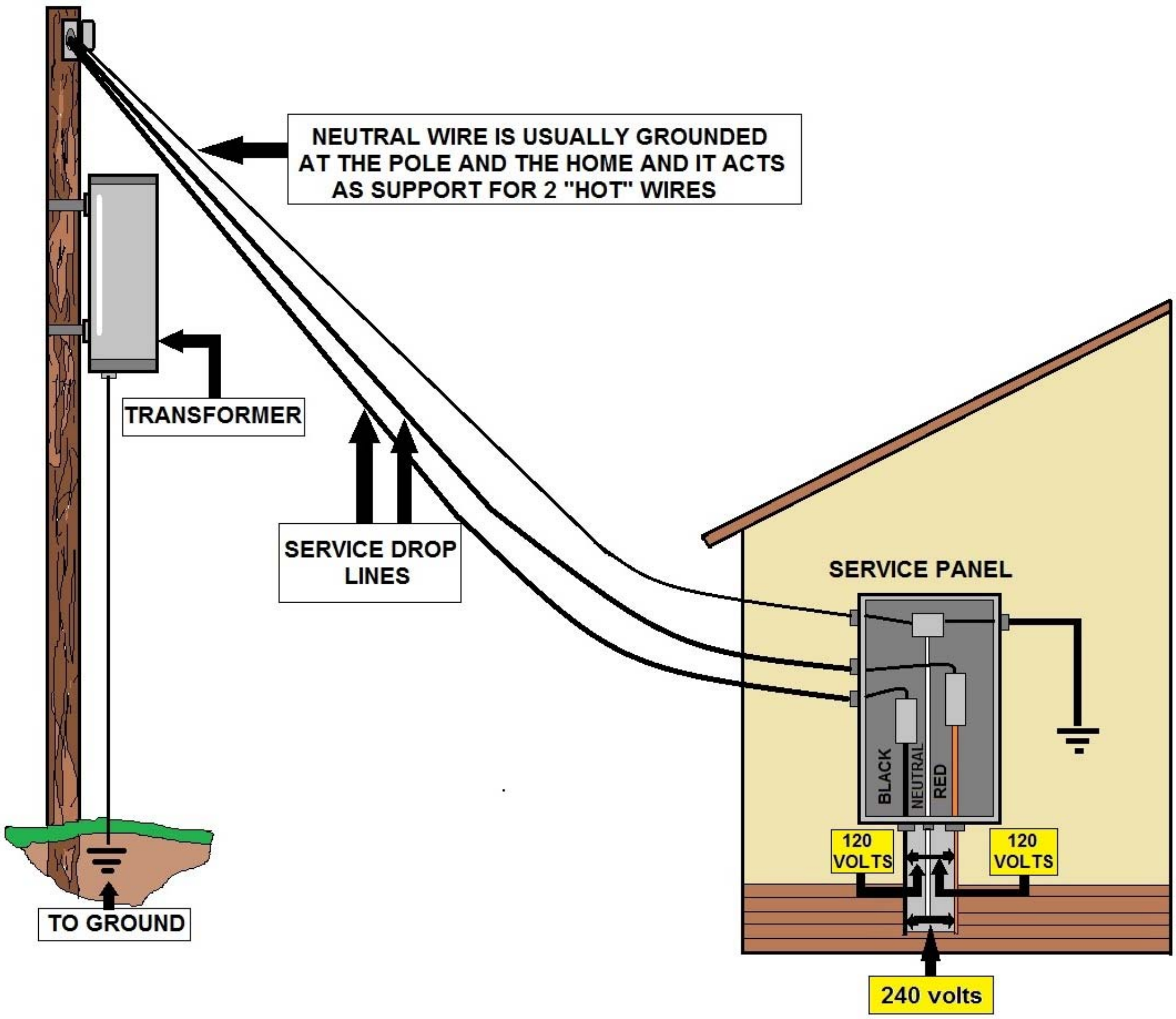
Grounded conductors are usually insulated, since there is the possibility of voltage on them in case of a bad connection.

A Grounding Wire, on the other hand, connects non-current-carrying metal parts of equipment to ground. It will have current in it only when a fault occurs, and then only briefly until a fuse blows or breaker trips. It is not usually sized to carry full load current. Do not connect loads between a hot conductor and a grounding wire. Grounding wires are often uninsulated.

Often, metal parts are grounded through the conduit, cable trays, busways, or metal frames of equipment, and there may be no separate equipment grounding wire. The connection to ground is often at a water pipe, or steel building frame. Some installations include a grounding rod driven in to the earth. Neither a grounding wire nor a grounded conductor must ever be fused, switched, or broken in any way. The connection to ground must be secure and permanent.

Color Coding

- The NEUTRAL grounded return wire is always WHITE or GRAY.
- The HOT wires are usually BLACK or RED.
- The GROUNDING wire, if one is used, is GREEN or uninsulated.



BASIC HOME ELECTRICITY
(120/240 volts)

Transformer Basic Principals

A simple transformer consists of two electrical conductors called the **primary winding** and **secondary winding**, and a steel core that magnetically links them together.

These two windings can be considered as a pair of mutually coupled coils. Energy is coupled between the windings by the magnetic field that links both primary and secondary windings.

Ideal Transformer

The assumptions to characterize the ideal transformer are:

- The windings of the transformer have no resistance. Thus, there is no copper loss in the winding, and hence no voltage drop.
- Flux is confined within the magnetic core. Therefore, it is the same flux that links the input and output windings.
- Permeability of the core is infinitely high which implies that net mmf (amp-turns) must be zero (otherwise there would be infinite flux) hence $I_P N_P - I_S N_S = 0$.
- The transformer core does not suffer magnetic hysteresis or eddy currents, which cause inductive loss.

If the secondary winding of an ideal transformer has no load, no current flows in the primary winding.

The circuit diagram (right) shows the conventions used for an ideal, i.e. lossless and perfectly-coupled transformer having primary and secondary windings with N_P and N_S turns, respectively.

The ideal transformer induces secondary voltage V_S as a proportion of the primary voltage V_P and respective winding turns as given by the equation

$$\frac{V_P}{V_S} = \frac{N_P}{N_S} = a,$$

where,

a is the winding *turns ratio*, the value of these ratios being respectively higher and lower than unity for step-down and step-up transformers,

V_P designates source impressed voltage,

V_S designates output voltage, and,

According to this formalism, when the number of turns in the primary coil is greater than the number of turns in the secondary coil, the secondary voltage is smaller than the primary voltage. On the other hand, when the number of turns in the primary coil is less than the number of turns in the secondary, the secondary voltage is greater than the primary voltage.
Any load impedance Z_L connected to the ideal transformer's secondary winding allows energy to flow without loss from primary to secondary circuits. The resulting input and output apparent power are equal as given by the equation

$$I_P V_P = I_S V_S.$$

Combining the two equations yields the following ideal transformer identity

$$\frac{V_P}{V_S} = \frac{I_S}{I_P} = a.$$

This formula is a reasonable approximation for the typical commercial transformer, with voltage ratio and winding turns ratio both being inversely proportional to the corresponding current ratio.

The load impedance Z_L and secondary voltage V_S determine the secondary current I_S as follows

$$I_S = \frac{V_S}{Z_L}.$$

The apparent impedance Z_L' of this secondary circuit load *referred* to the primary winding circuit is governed by a squared turns ratio multiplication factor relationship derived as follows

$$Z_L' = \frac{V_P}{I_P} = \frac{aV_S}{I_S/a} = a^2\frac{V_S}{I_S} = a^2 Z_L.$$

For an ideal transformer, the power supplied to the primary and the power dissipated by the load are equal. If $Z_L = R_L$ where R_L is a pure resistance then the power is given by:

$$P = \frac{V_\mathrm{S}^2}{R_\mathrm{L}} = \frac{V_\mathrm{P}^2}{a^2 R_\mathrm{L}}$$

The primary current is given by the following equation:

$$I_\mathrm{P} = \frac{V_\mathrm{P}}{a^2 Z_L}$$

Induction Law

A varying electrical current passing through the primary coil creates a varying magnetic field around the coil which induces a voltage in the secondary winding. The primary and secondary windings are wrapped around a core of very high magnetic permeability, usually iron, so that most of the magnetic flux passes through both the primary and secondary coils. The current through a load connected to the secondary winding and the voltage across it are in the directions indicated in the figure.

Ideal transformer and induction law

The voltage induced across the secondary coil may be calculated from Faraday's law of induction, which states that:

$$V_\mathrm{S} = N_\mathrm{S}\frac{\mathrm{d}\Phi}{\mathrm{d}t}.$$

where

V_s is the instantaneous voltage, N_s is the number of turns in the secondary coil, and dΦ/dt is the derivative of the magnetic flux Φ through one turn of the coil. If the turns of the coil are oriented perpendicularly to the magnetic field lines, the flux is the product of the magnetic flux density *B* and the area *A* through which it cuts. The area is constant, being equal to the cross-sectional area of the transformer core, whereas the magnetic field varies with time according to the excitation of the primary.

Since the same magnetic flux passes through both the primary and secondary coils in an ideal transformer, the instantaneous voltage across the primary winding equals

$$V_{\mathrm{P}} = N_{\mathrm{P}} \frac{\mathrm{d}\Phi}{\mathrm{d}t}.$$

Taking the ratio of the above two equations gives the same voltage ratio and turns ratio relationship shown above, that is,

$$\frac{V_{\mathrm{P}}}{V_{\mathrm{S}}} = \frac{N_{\mathrm{P}}}{N_{\mathrm{S}}} = a.$$

The changing magnetic field induces an emf across each winding. The primary emf, acting as it does in opposition to the primary voltage, is sometimes termed the counter emf. This is in accordance with Lenz's law, which states that induction of emf always opposes development of any such change in magnetic field.

As still lossless and perfectly-coupled, the transformer still behaves as described above in the ideal transformer.

Polarity

The relationships of the instantaneous polarity at each of the terminals of the windings of a transformer depend on the direction the windings are wound around the core. Identically wound windings produce the same polarity of voltage at the corresponding terminals. This relationship is usually denoted by the dot convention in transformer circuit diagrams, nameplates, and on terminal markings, which marks the terminals having an in-phase relationship.

Real Transformer

The ideal transformer model neglects the following basic linear aspects in real transformers.
Core losses, collectively called magnetizing current losses, consist of

- Hysteresis losses due to nonlinear application of the voltage applied in the transformer core, and
- Eddy current losses due to joule heating in the core that are proportional to the square of the transformer's applied voltage.

Whereas windings in the ideal model have no impedance, the windings in a real transformer have finite non-zero impedances in the form of:

- Joule losses due to resistance in the primary and secondary windings.
- Leakage flux that escapes from the core and passes through one winding only resulting in primary and secondary reactive impedance.

If a voltage is applied across the primary terminals of a real transformer while the secondary winding is open without load, the real transformer must be viewed as a simple inductor with an impedance Z:

$$Z_P = j\omega L_P$$
$$I_{\mathrm{P}} = V_{\mathrm{P}}/Z_{\mathrm{P}}.$$

Delta-Wye Transformer

A **delta-wye transformer** is a type of three-phase electric power transformer design that employs delta-connected windings on its primary and wye/star connected windings on its secondary. A neutral wire can be provided on wye output side. It can be a single three-phase transformer, or built from three independent single-phase units. An equivalent term is **delta-star transformer**.

Delta-wye transformers are common in commercial, industrial, and high-density residential locations, to supply three-phase distribution systems.

An example would be a distribution transformer with a delta primary, running on three 11 kV phases with no neutral or earth required, and a star (or wye) secondary providing a 3-phase supply at 415 V, with the domestic voltage of 240 available between each phase and the earthed (grounded) neutral point.

The delta winding allows third-harmonic currents to circulate within the transformer, and prevents third-harmonic currents from flowing in the supply line. Delta connected windings are not common for higher transmission voltages (138 kV and above) owing to the higher cost of insulation compared with a wye connection.

Delta-wye transformers introduce a 30, 150, 270 or 330 degree phase shift. Thus they cannot be paralleled with wye-wye (or delta-delta) transformers. However, they can be paralleled with identical configurations and some different configurations of other delta-wye (or wye-delta with some attention) transformers

Transformer Classifications

Transformers are adapted to numerous engineering applications and may be classified in many ways:

- By power level (from fraction of a VA to over a thousand MVA),
- By application (power supply, impedance matching, circuit isolation),
- By frequency range (power, audio, RF)
- By voltage class (a few volts to about 750 kilovolts)
- By cooling type (air cooled, oil filled, fan cooled, water cooled, etc.)
- By purpose (rectifier, arc furnace, amplifier output, etc.)
- By ratio of the number of turns in the coils -
    - **Step up**
    - **Step down**
    - **Isolating**
    - **Variable**

Single-Phase Loads

Single-phase loads may be connected across any two phases, or a load can be connected from phase to neutral. Distributing single-phase loads among the phases of a three-phase system balances the load and makes most economical use of conductors and transformers.

In a symmetrical three-phase four-wire, wye system, the three phase conductors have the same voltage to the system neutral.

The voltage between line conductors is $\sqrt{3}$ times the phase conductor to neutral voltage.

$$V_{L\text{-}L} = \sqrt{3}\, V_{L\text{-}N}$$

The currents returning from the customers' premises to the supply transformer all share the neutral wire. If the loads are evenly distributed on all three phases, the sum of the returning currents in the neutral wire is approximately zero. Any unbalanced phase loading on the secondary side of the transformer will use the transformer capacity inefficiently.

If the supply neutral is broken, phase-to-neutral voltage is no longer maintained. Phases with higher relative loading will experience reduced voltage and phases with lower relative loading will experience elevated voltage, up to the phase-to-phase voltage.

A high-leg delta provides phase-to-neutral relationship of $V_{L\text{-}L} = 2\, V_{L\text{-}N}$, however, L-N load is imposed on one phase.

A transformer manufacturer's page suggests that L-N loading to not exceed 5% of transformer capacity.

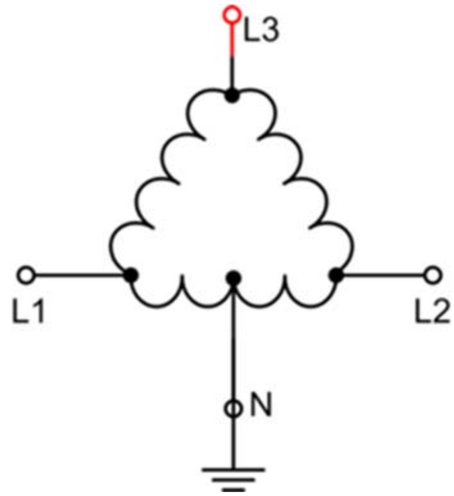
$\sqrt{3}$ is ≈ 1.73, so if $V_{L\text{-}N}$ was defined as 100%, $V_{L\text{-}L}$ would be ≈ 100% × 1.73 = 173% If $V_{L\text{-}L}$ was set as 100%, then $V_{L\text{-}N}$ ≈ 57.7%

Unbalanced Loads
When the currents on the three live wires of a three-phase system are not equal or are not at an exact 120° phase angle, the power-loss is greater than for a perfectly balanced system. The degree of imbalance is expressed by symmetrical components.

Three-phase systems are evaluated at generating stations and substations in terms of these three components, of which two are zero in a perfectly balanced system.

Non-linear Loads
With linear loads, the neutral only carries the current due to imbalance between the phases. Devices that utilize rectifier-capacitor front-end such as switch-mode power supplies, computers, office equipment and such produce third order harmonics that are in-phase on all the supply phases. Consequently, such harmonic currents add in the neutral which can cause the neutral current to exceed the phase current.

Three-Phase Loads



A transformer for a high-leg delta system; 200 V 3-phase motors would be connected to L1, L2 and L3. 200 V Single-phase load would be connected L1 and L2. Single phase 100 V load between either L1 or L2 and neutral (N). L3 (wild or high leg) will be 173.2 V to neutral.

An important class of three-phase load is the electric motor. A three-phase induction motor has a simple design, inherently high starting torque and high efficiency. Such motors are applied in industry for many applications.

A three-phase motor is more compact and less costly than a single-phase motor of the same voltage class and rating and single-phase AC motors above 10 HP (7.5 kW) are uncommon. Three-phase motors also vibrate less and hence last longer than single-phase motors of the same power used under the same conditions.

Line frequency flicker in light can be reduced by evenly spreading three phases across line frequency operated light sources so that illuminated area is provided light from all three phases. The effect of line frequency flicker is detrimental to super slow motion cameras used in sports event broadcasting.

Three phase lighting has been applied successfully at the 2008 Beijing Olympics to provide consistent light level for each frame for SSM cameras. Resistance heating loads such as electric boilers or space heating may be connected to three-phase systems. Electric lighting may also be similarly connected.

Rectifiers may use a three-phase source to produce a six-pulse DC output. The output of such rectifiers is much smoother than rectified single phase and, unlike single-phase, does not drop to zero between pulses. Such rectifiers may be used for battery charging, electrolysis processes such as aluminum production or for operation of DC motors. "Zig-zag" transformers may make the equivalent of six-phase full-wave rectification, twelve pulses per cycle, and this method is occasionally employed to reduce the cost of the filtering components, while improving the quality of the resulting DC.

Alternatives to Three-Phase

- Split-phase electric power is used when three-phase power is not available and allows double the normal utilization voltage to be supplied for high-power loads.

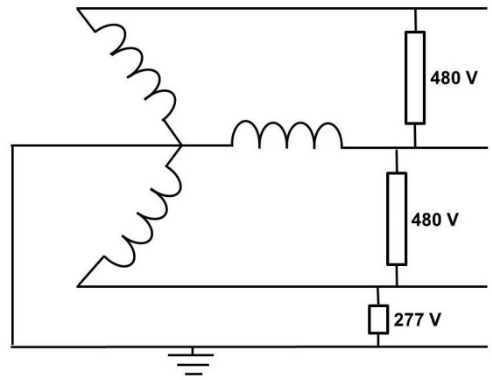
- Two-phase electric power, like three-phase, gives constant power transfer to a linear load. For loads that connect each phase to neutral, assuming the load is the same power draw, the two-wire system has a neutral current that is greater than neutral current in a three-phase system. Also motors are not entirely linear, which means that despite the theory, motors running on three-phase tend to run smoother than those on two-phase. The generators in the Adams Power Plant at Niagara Falls that were installed in 1895 were the largest generators in the world at the time and were two-phase machines. True two-phase power distribution is obsolete for "new work" applications, but still exists for "old work" applications, perhaps most particularly in Buffalo and Niagara Falls, NY, Toronto and Niagara Falls, Ontario, Philadelphia and Reading, PA, and Camden, NJ. "New work" three-phase installations may be supplied by old two-phase feeders, and "old work" two-phase installations may be supplied by new three-phase feeders using a Scott-T transformer, invented by Charles F. Scott. Special-purpose systems may use a two-phase system for frequency control.

- *Monocyclic power* was a name for an asymmetrical modified two-phase power system used by General Electric around 1897, championed by Charles Proteus Steinmetz and Elihu Thomson. This system was devised to avoid patent infringement. In this system, a generator was wound with a full-voltage single-phase winding intended for lighting loads and with a small fraction (usually 1/4 of the line voltage) winding that produced a voltage in quadrature with the main windings. The intention was to use this "power wire" additional winding to provide starting torque for induction motors, with the main winding providing power for lighting loads. After the expiration of the Westinghouse patents on symmetrical two-phase and three-phase power distribution systems, the monocyclic system fell out of use; it was difficult to analyze and did not last long enough for satisfactory energy metering to be developed.

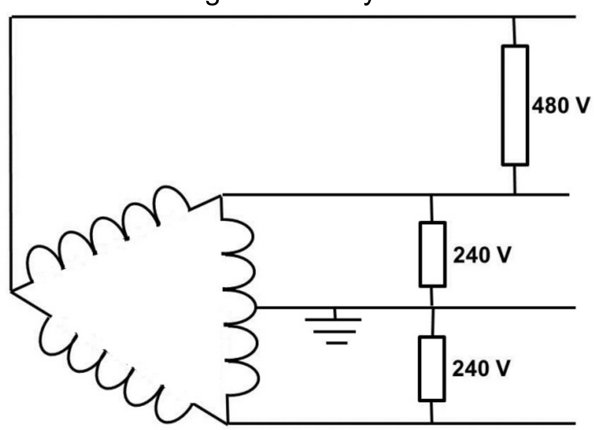
- High-phase-order systems for power transmission have been built and tested. Such transmission lines typically would use six phases or twelve phases. High-phase-order transmission lines allow transfer of slightly less than proportionately higher power through a given volume without the expense of a high-voltage direct current (HVDC) converter at each end of the line. However, they require correspondingly more pieces of equipment.

Powering Single-Phase Loads from 3-Phase Systems

Any 3-phase system has single-phase voltage between the powerlines that can be used to power single-phase loads at line-to-line voltage, or at some other voltage if a single-phase transformer is used.



Four-Wire Wye
If a grounded neutral conductor is connected to a wye junction, the system is called a four-wire wye. Single-phase loads can be connected between any powerline and the grounded neutral. The voltage available is line-to-line voltage divided by 1.73.



Four-Wire Delta
A four-wire delta system has a grounded neutral conductor connected to a center tap on one secondary winding.

Single-phase voltage equal to half of the line-to-line voltage is available between the powerline on either end of that winding and the grounded neutral.

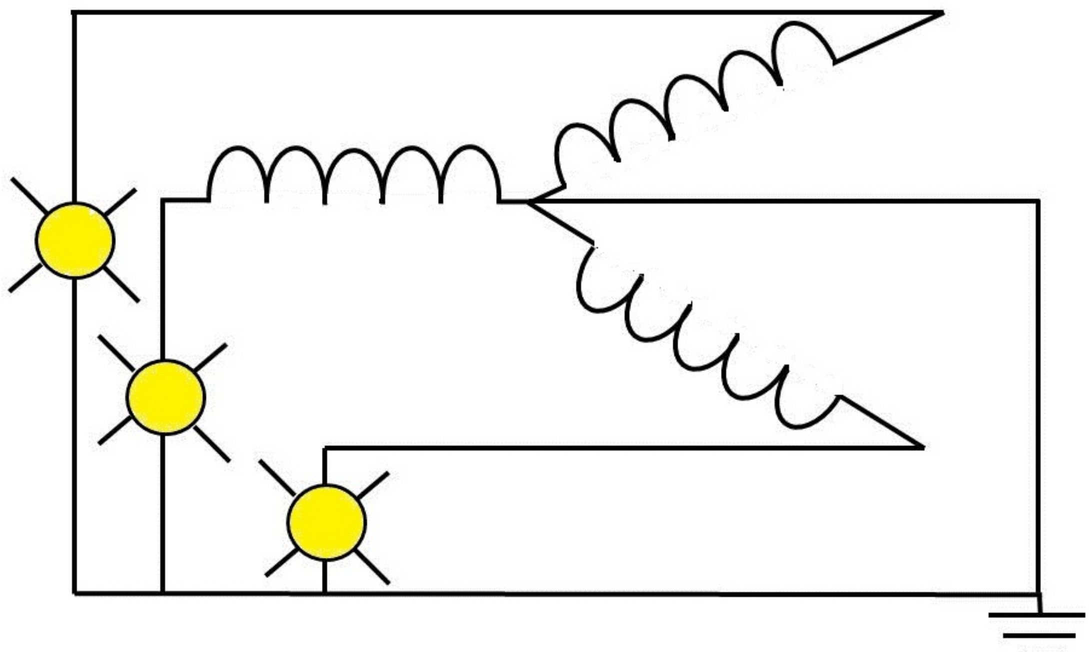
The voltage between the other phase conductor and the grounded neutral will be considerably higher than half line-to-line voltage. This 'high leg' or 'bastard voltage' is not normally used to power single-phase loads.

Measure phase-to-ground voltages before connecting single-phase loads between a phase conductor and a neutral conductor on any 4-wire system! If there is no neutral conductor, do not attempt to connect a single-phase load between one of the phase conductors and ground!

Single-phase loads powered by a three-phase system should be balanced between the lines as much as possible. In other words, the loads should be arranged so that the current in the 3-phase conductors is as nearly equal as possible.

Current in the neutral will be zero if single-phase loads connected between the phase lines and a grounded neutral are perfectly balanced.

Practice Exercise
Single-phase lighting loads are connected between the phase lines and a grounded neutral of a 4-wire wye system.



1. If the neutral conductor is cut,

A. All the lights will go out.

B. Voltages on the lights will be unequal unless they were perfectly balanced.

C. The system will operate normally because the ground will carry the unbalanced current.

D. Each light will receive three-phase power instead of single-phase.

2. 1f the neutral ground at the transformer is disconnected,

A. The system will operate normally.

B. All the lights will go out.

C. Unbalanced currents will not cancel.

D. The voltage to ground on all three phases win rise to line-to-line Voltage.

Connecting Loads

1. Most lights require single-phase power. There are usually just two supply terminals or leads. One, usually black, is designated for the hot conductor and the other, white or grey for grounded neutral.

Industrial heaters, ovens, and dryers, may require single or three-phase power. Connection is usually simple, although dual voltage devices may need jumpers added or removed. There are no phase sequence or polarity complications.

2. Many small, single speed, single-phase motors can operate on either 115 or 230 volts by connecting different terminals, or by adding or removing a jumper.

If there is a choice of which voltage to use, connect the motor for 230 volts; it will draw only half as much current at the higher voltage, and line losses will be less.

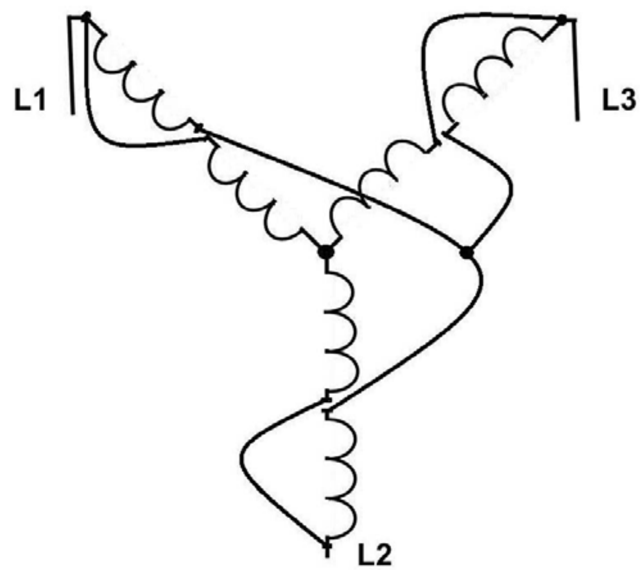
Both conductors to the motor will be hot. Polarity usually makes no difference; the motor will run equally well and in the same direction with the leads reversed.

If connected for 115 volts, one conductor will be grounded. One of the leads or terminals may be designated for the grounded conductor because of the way the motor is insulated.

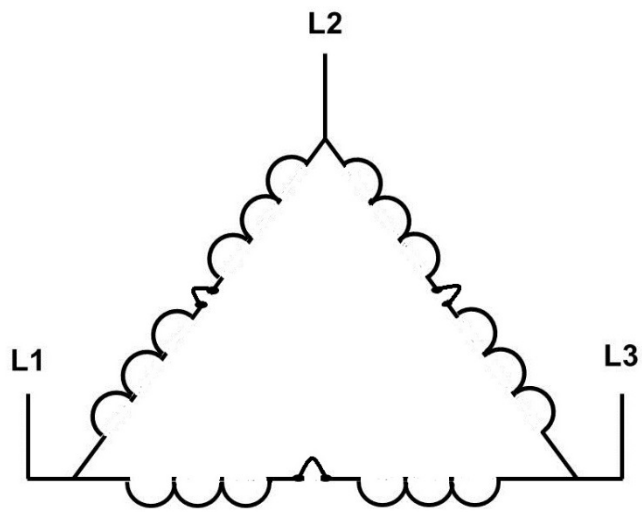
Multiple speed single-phase motors may have six or more terminals or leads. A schematic of the motor windings and a diagram of the lead or terminal connections is essential for correct wiring.

3. Three-phase motors must have three properly sequenced voltages of the correct polarity.

Most common three-phase induction motors are dual voltage units. Each of the three windings is divided, so that there is a pair of windings for each phase. The windings may be connected internally for either wye or delta. In both cases there are nine terminals or leads.



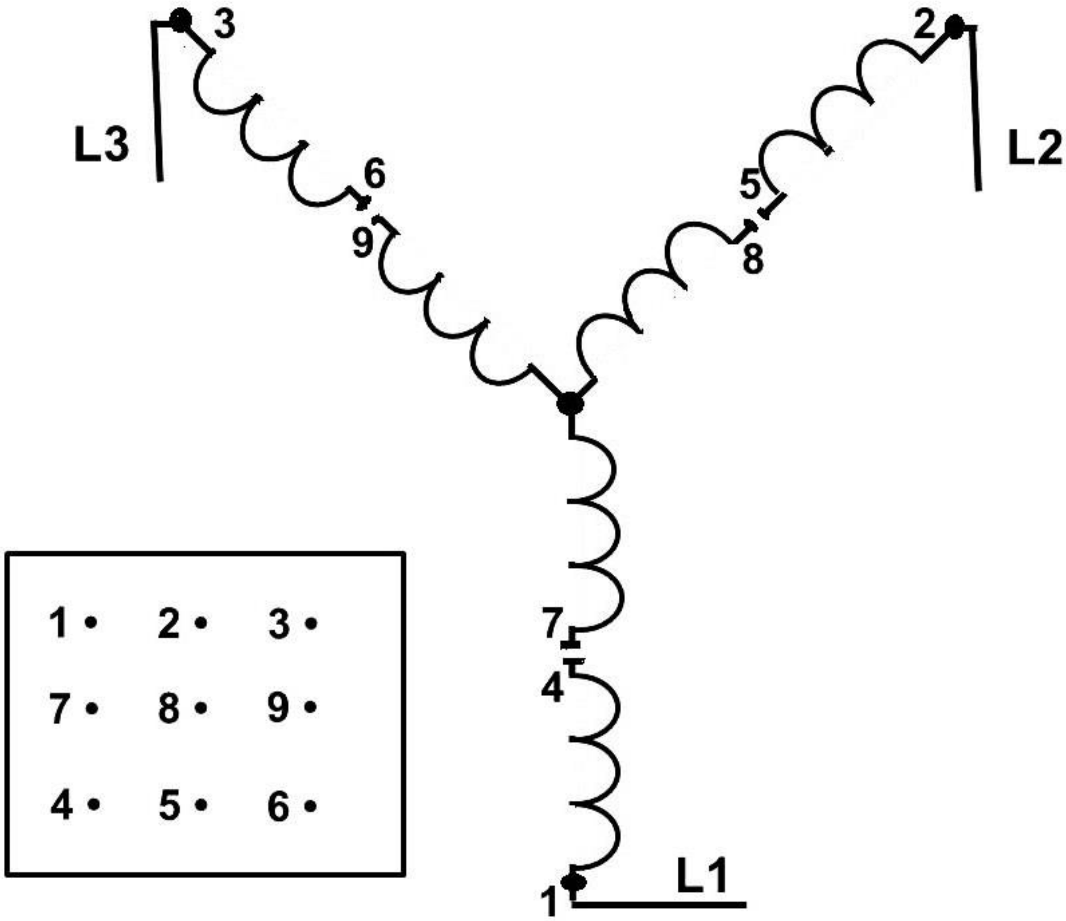
For low voltage, the leads or terminals are jumpered to connect the winding pairs in parallel, as illustrated in this wye motor.



For high voltage, the leads or terminals are jumpered to connect the windings in series, as illustrated in this delta motor.

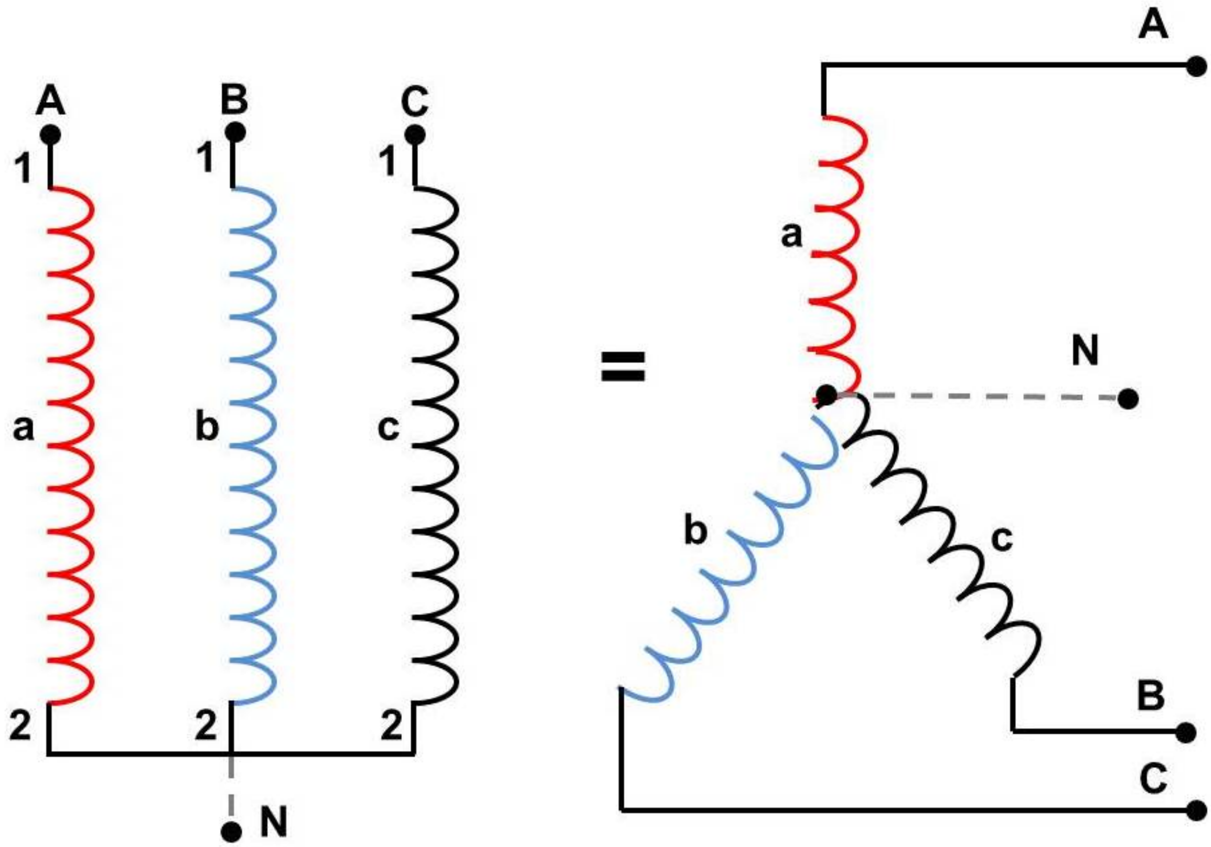
Usually, the terminals or leads are well marked, though occasionally it may be necessary to determine which leads or terminals are which.

Practice Exercise



Above is the schematic for a dual voltage wye connected motor, and its terminal board.

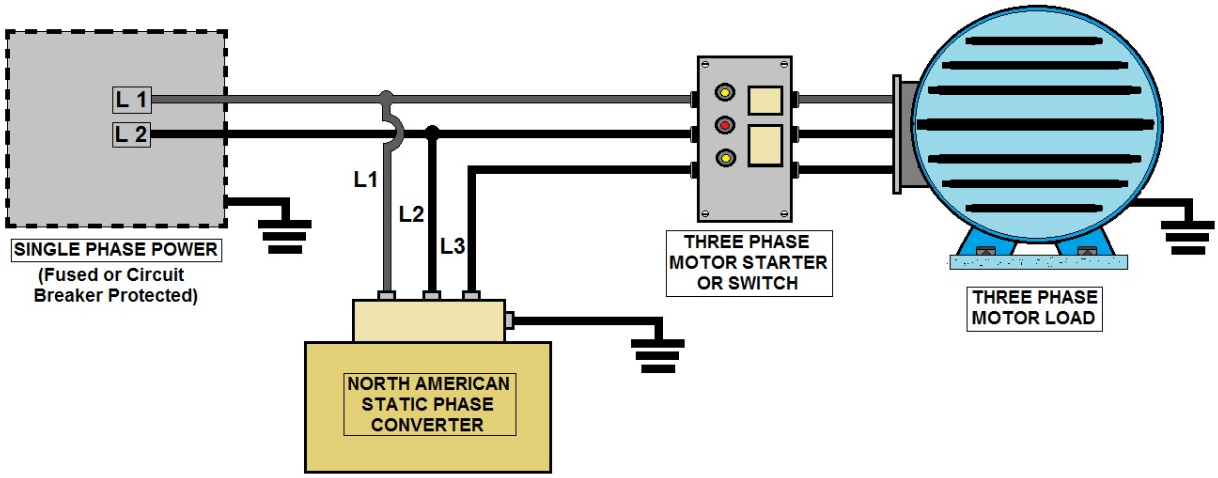
Connect the motor for high voltage. Show connections both on the motor schematic, by connecting the windings to each other, and on terminal board by drawing in the correct jumpers and the three phase lines.



STAR CONNECTION

Phase Converter

A **phase converter** is a device that converts electric power provided as single phase to multiple phase or vice versa. The majority of phase converters are used to produce three-phase electric power from a single-phase source, thus allowing the operation of three-phase equipment at a site that only has single-phase electrical service. Phase converters are used where three-phase service is not available from the utility, or is too costly to install due to a remote location. A utility will generally charge a higher fee for a three-phase service because of the extra equipment for transformers and metering and the extra transmission wire.



ELECTRICAL PHASE CONVERTER DIAGRAM

Conversion Systems

Three phase induction motors may operate adequately on an unbalanced supply if not heavily loaded. This allows various imperfect techniques to be used. A single-phase motor can drive a three-phase generator, which will produce a high-quality three-phase source but with high cost for apparatus. Several methods exist to run three-phase motors from a single-phase supply, these can in general be classified as:

- Electronic means of creating three phase where the incoming power is rectified, and the three phase power is synthesized with electronics. Power electronic devices directly produce a three-phase waveform from single-phase power, using a rectifier and inverter combination. This also offers the advantage of variable frequency.
- A digital phase converter uses a rectifier and inverter to create a single voltage with power electronics, which is added to the two legs of the single-phase source to create three-phase power. Unlike a phase converting VFD, it cannot vary the frequency and motor speed since it generates only one leg which must match the voltage and frequency of the single-phase supply. It does have the advantage of a sine-wave output voltage and excellent voltage balance between the phases.
- Rotary phase converters constructed from a three-phase electric motor or generator "idler". These normally require some kind of starting aid and capacitors to improve phase balance and power factor. This is a two motor solution. One motor is not connected to a load and produces the three phase power; the second motor driving the load runs on the power produced.

- Static conversion techniques in which the motor is run at less than full efficiency mainly on two of the legs of the three phase motor. Current is sometimes injected into the third leg with a capacitor or transformer arrangements that provide imperfect phase shift. In these systems the motor must be de-rated.
- Methods in which the connection of the windings of the motor, normally a wye and or delta configurations, are replaced with novel connections. These techniques are covered in patents of Dr. Otto J. M. Smith, such as US Patent 5,545,965.

Digital Phase Converter

A *digital phase converter* creates a three phase power supply from a single phase supply. A digital signal processor (DSP) is used to control power electronic devices to generate a third voltage, which along with the single-voltage from the supply creates a balanced three-phase power supply.

AC power from the utility is converted to DC, then back to AC. The power switching devices used in this process are insulated gate bipolar transistors (IGBT).

In one type of digital phase converter the input rectifier consists of IGBTs in series with inductors. The IGBTs are controlled by software in the DSP to draw current from the single-phase line in a sinusoidal fashion, charging capacitors on a constant voltage DC bus. Because the incoming current is sinusoidal, there are no significant harmonics generated back onto the line as there are with the rectifiers found in most VFDs. The controlled rectifier input allows power factor correction.

The output inverter consists of IGBTs that draw on the power of the DC bus to create an AC voltage. A voltage created by power switching devices like IGBTs is not sinusoidal. It is a pulse-width modulated (PWM) waveform very high in harmonic distortion. This PWM voltage is then passed through an inductor/capacitor filter system that produces a sine wave voltage with less than 3% total harmonic distortion (standards for computer grade power allow up to 5% THD).

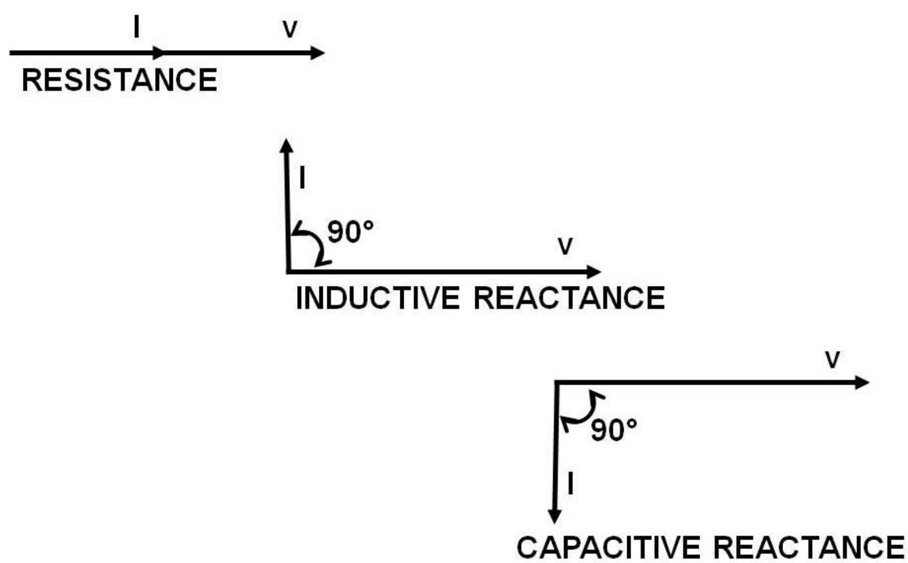
By contrast, VFDs generate a PWM voltage that limits their versatility and makes them unsuitable for many applications. Software in the DSP continually monitors and adjusts this generated voltage to produce a balanced three-phase output at all times. It also provides protective functions by shutting down in case of utility over-voltage and under-voltage or a fault. With the ability to adjust to changing conditions and maintain voltage balance, a digital phase converter can safely and efficiently operate virtually any type of three-phase equipment or any number of multiple loads.

Phasors

The impedance of circuits which combine reactive and resistive components can be calculated using phasors. A phasor is an arrow or vector which can be used to represent impedance, or current graphically.

1. The length of the phasor arrow on the graph is proportional to the impedance, current or voltage.

2. The direction of the phasor arrow represents phase relationship. If the voltage across-a component is taken as a reference, the current phasor will point the same way if the component is a resistor, since voltage and current are in-phase.



So if the voltage phasor points, like the hand of a clock, at 3:00 o'clock, the current phasor will also point at 3:00.

But the current phasor will point up at 12:00 if the component is a coil, and down at 6:00 if the component is a capacitor. This makes sense if you remember that the current in a coil will follow along 90 degrees behind, and the current in a capacitor is 90 degrees ahead of the voltage.

When drawing phasors, remember that:
3. Phasor arrows can be placed on the graph head to tail in any order, as long as their length and direction are correct.

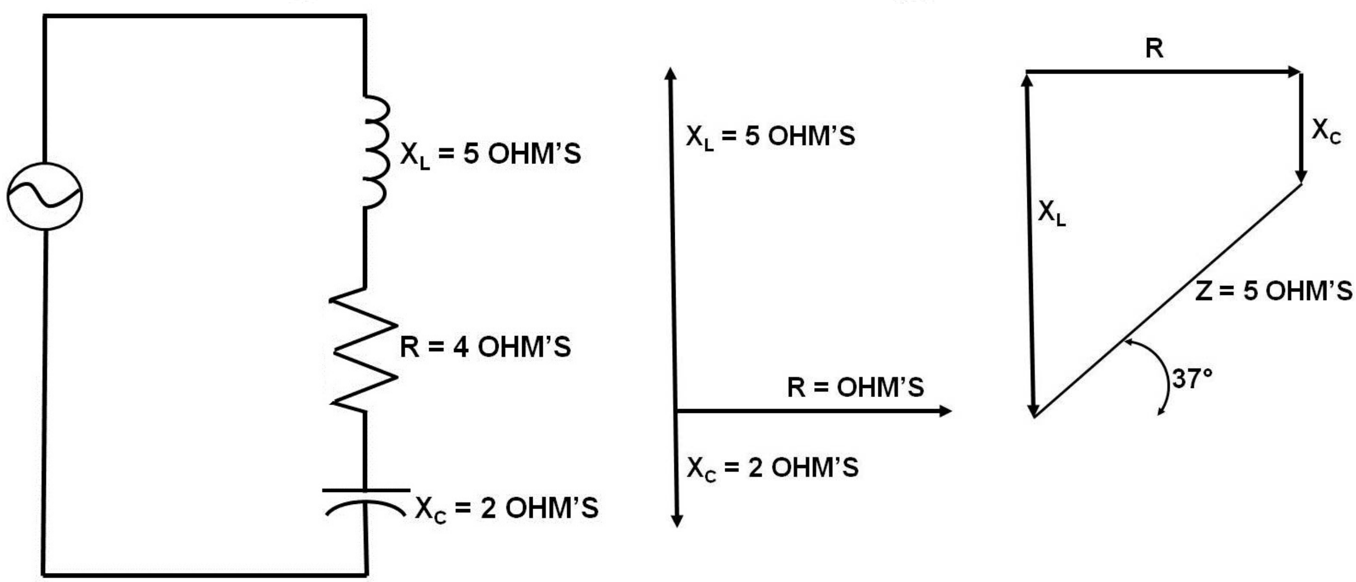
4. The combination of phasor arrows is a single arrow from the tail of the first arrow to the head of the last arrow.

To find the equivalent impedance of a circuit including different kinds of reactances and resistances, use impedance phasors. Like current phasors, where voltage is taken as a reference,

- the impedance of a resistive component is shown by an arrow pointing to the right.
- the impedance of an inductive component is shown by an arrow pointing up.
- the impedance of a capacitive component is shown by an arrow pointing down.

Example:
The impedances of the inductor, of the resistor, and of the capacitor, are represented by the phasor arrows labelled

$$\frac{X}{L} \ \mathbf{x\ R} \quad \textit{and} \quad \frac{X}{C}$$



a) Connect the arrows head to tail in any order.

b) Connect the starting point to the head of the last arrow.

c) Measure the length of the resulting phasor arrow; this represents the circuit impedance, in ohms.

d) Measure the angle of the resulting phasor angle; this angle represents the angle of the current and the voltage.

In other words, this series combination of components has an impedance of 5 ohms, and the current in the circuit will lag behind the voltage about 37 degrees.

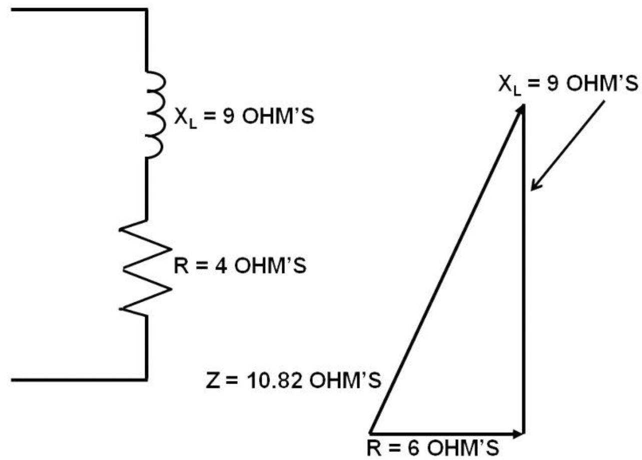
If you know that resistive part of the impedance and the reactive part, you can calculate the total impedance from the formula

$$Z^2 = R^2 + \frac{X^2}{L}$$

In a circuit like this, for example, the total 9 ohms impedance, Z would equal the square root of 6 ohms squared plus 9 ohms squared, or 10.82 ohms.

$$Z^2 = 6^2 + 9^2$$

$$Z = 10.82 \text{ OHM'S}$$



Power in Reactive Circuits
In a purely resistive load, current is always in phase with the voltage. This means, that if you measure the voltage across a heater and measure the current being drawn, you can' use the formula

$$P = I \times V$$

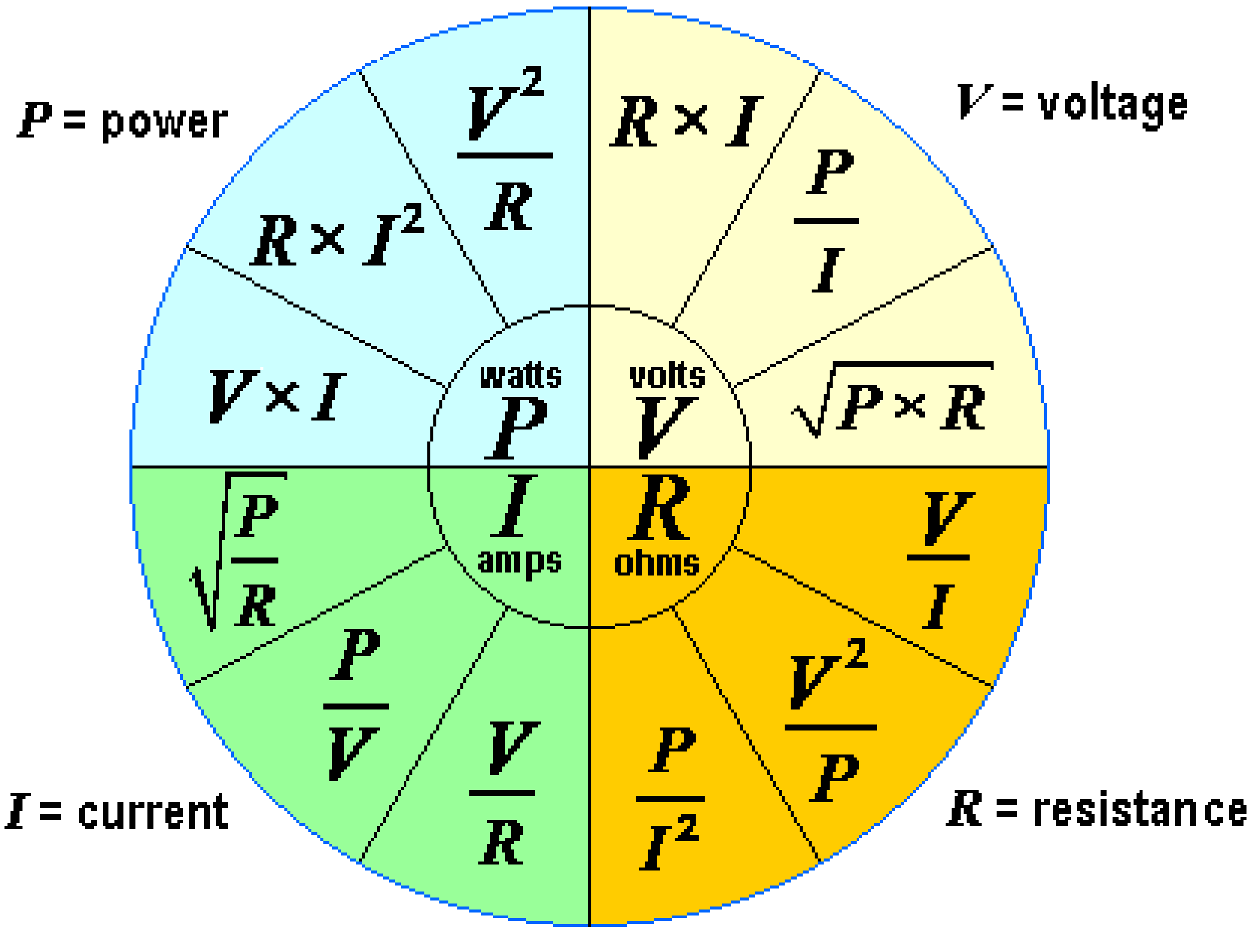
to determine how many watts of 'power are being consumed.

However, if you took measurements on a motor or other reactive load, you would find that multiplying current times voltage would give a result that is higher than the real 'power being consumed. If you checked your answer with a watt meter you would discover a significant difference.

The reason is that the current and voltage in the inductive reactance of the motor, do not contribute to power consumption.

Simply multiplying the current and voltage readings on the motor will result in Apparent Power, not real power.

The lower reading from the watt meter is the Real Power being consumed by the resistive impedance of the motor.


P = power
V = voltage
I = current
R = resistance
watts
P
volts
V
I
amps
R
ohms
$\frac{V^2}{R}$
$R \times I^2$
$V \times I$
$R \times I$
$\frac{P}{I}$
$\sqrt{P \times R}$
$\sqrt{\frac{P}{R}}$
$\frac{P}{V}$
$\frac{V}{R}$
$\frac{V}{I}$
$\frac{V^2}{P}$
$\frac{P}{I^2}$

Power Factor

Power factor is the ratio between Real Power and Apparent Power. It is also the ratio between the resistive part of impedance and total impedance.

$$\text{POWER FACTOR} = \frac{\text{REAL POWER}}{\text{APPARENT POWER}} = \frac{R}{Z}$$

When the load impedance is not purely resistive (power factor = 1) there is out-of phase current in the lines which does no work. This extra current increases line losses. Larger generators and conductors are necessary to produce and send it.

Power companies sometimes charge a rate penalty for out-of-phase current. Power users therefore try to keep their power factor as close to 1 as possible.

Power factor can be read directly with a power factor meter. It can also be calculated from voltage, current and power meter readings.

$$\text{POWER FACTOR} = \frac{\text{REAL POWER}}{\text{APPARENT POWER}} = \frac{\text{WATTS}}{\text{I (A) X V}} = \frac{\text{1920 W}}{\text{5 A x 480 V}} = 0.8$$

For example, if a watt meter showed a motor consuming 1,920 watts, but an ammeter and voltmeter showed 5 amps at 480 volts, the power factor would be 0.8.

- Most reactive loads in industry are coils, so current lags voltage. To bring power factor closer to 1, capacitors of the right value are wired in parallel with motor circuits. Their capacitive reactance, where current leads voltage, offsets the inductive reactance of the calls.

Answers to Practice Exercises

Practice Exercise A

1. The inductive reactance of a coil is 6.28 times the frequency times the inductance of the coil in henrys. Since 500 millihenrys = 0.5 henry, the calculation is:

$$X_L = 6.28 \times 60 \times 0.5 = 188.4 \text{ ohms}$$

This assumes that the resistance of the coil is negligible. If it is not, then the resistance would have to be figured into the total impedance.

2. The impedance of any circuit, whatever the frequency of the AC, is simply voltage divided by current.

$$Z = V/I = 240/3 = 80 \text{ ohms}$$

Practice Exercise B

Capacitor b, with a capacitance of 650 microfarads} has a lower capacitive reactance than capacitor a, with *350* microfarads. The formula for capacitive reactance is

$$X_c = \frac{1}{6.28 \times f \times c}$$

So the larger the capacitance, the lower the capacitive reactance, and the more AC flows through it with a given voltage.

Practice Exercise C

1. Each 2 millihenry coil will have a 'reactance of 6.28 x 60 x 0.002 = 0.7536 ohms.

Reactance, like anything measured in .ohms, adds in series circuits, so the combination of the two coils will be 0.7536 + 0.7536 = *1.5072* ohms.

2. Each 10 mfd capacitor will have a capacitive reactance of

1/6.28 x 60 x 0.00001 =265.4 ohms.

The current in each capacitor will be the source voltage divided by 265.4 ohms (600/265.4 = 2.26 amperes). The total current will be the sum of both currents, 2.26 + 2.26 = 4.52 amperes.

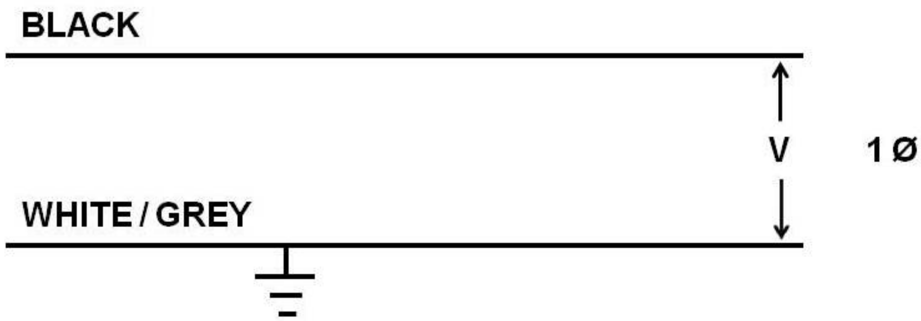
NOTE: Inductances of coils add in series like resistance, so we could have calculated the reactance of a single 4 millihenry coil In parallel, inductances must be divided into 1 before being added, like resistances. However, the capacitance of capacitors *adds in parallel,* so we could have treated the 2 capacitors as one 20 mfd capacitor. In series, unlike inductance and resistance, capacitance must be divided into 1 before being added.

Single and Three-Phase Power Sources

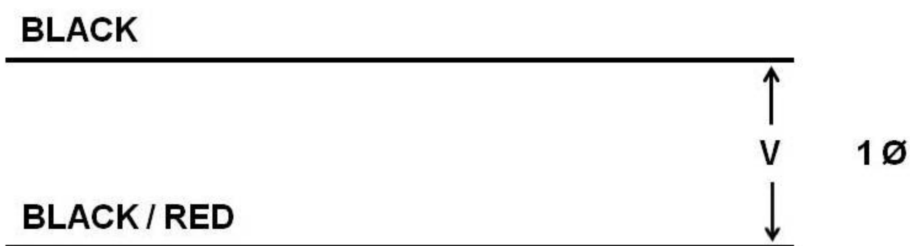
Before you can connect anything-a load, control device, or transformer-to AC power lines, you need to know whether you have single- or three-phase power, and what kind of source produces it.

Ultimately, the source of most AC power is an alternator. In practice, the local source is nearly always, the secondary side of a transformer system. Distribution transformers at the local or plant substation usually provide 1100 to 13,600 volts. Low voltage service drop transformers provide voltages between 120 and 600.

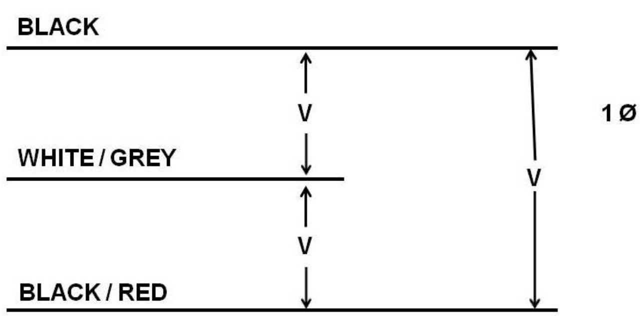
You may find one of several supply line combinations:



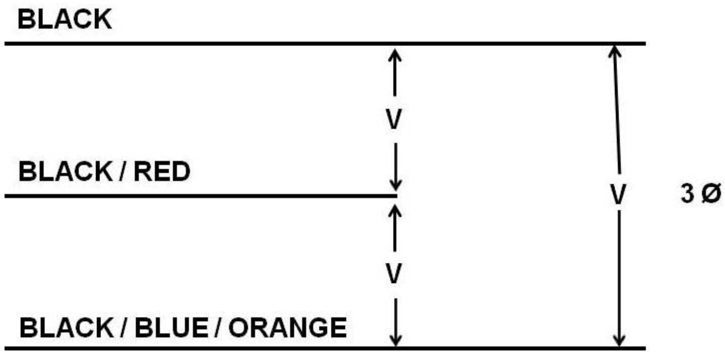
a) If there is only one hot conductor (usually black) and + one grounded conductor (white or grey), single- phase power is available between them.



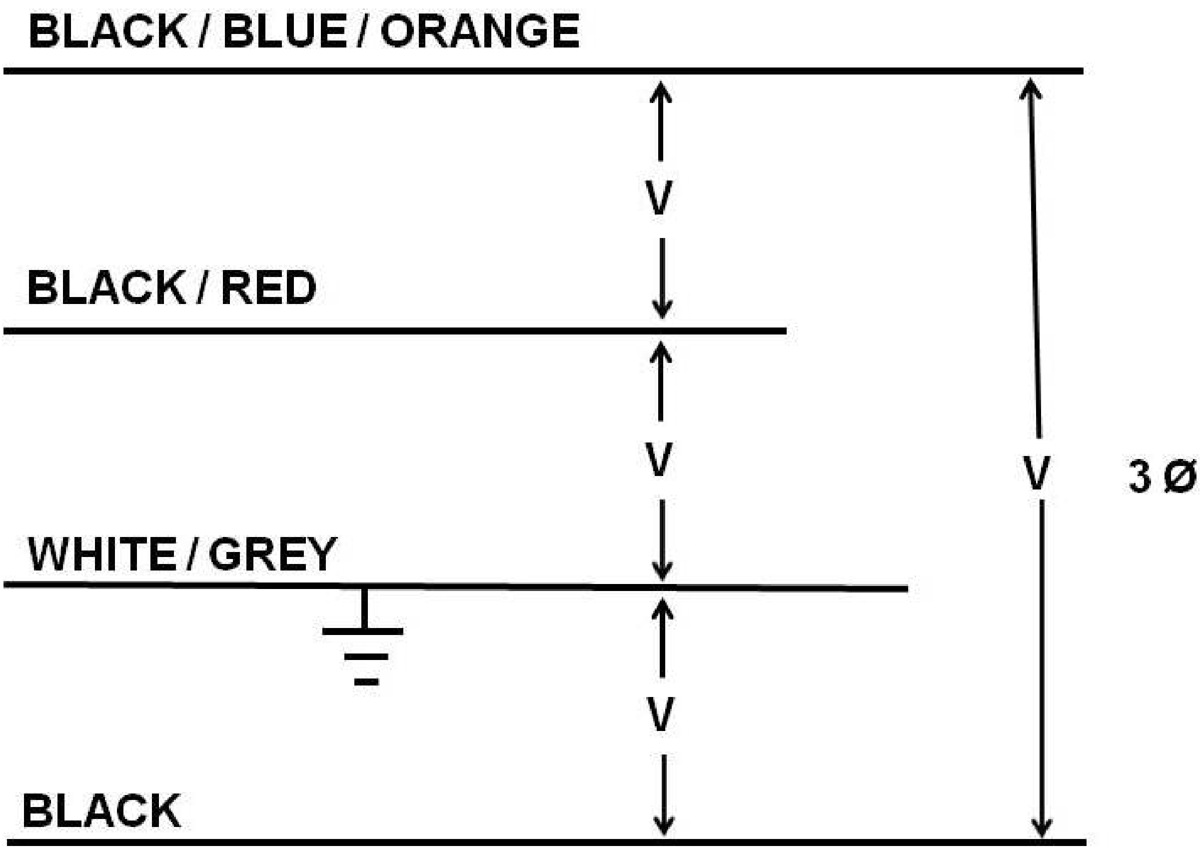
b) If there are two hot conductors (both black, or one black, black and one red), single-phase power is available between them.



c) If there are two hot conductors and a grounded neutral conductor, single-phase power is available between the hot conductors, and (at a lower voltage) between either hot conductor and the neutral conductor. This is the single-phase 3-wire Edison system.



d) If there are three hot conductors, the source is three-phase. Single-phase power is available between any black two of the conductors. Connection of three-phase loads to all three hot conductors provides three- phase power. Voltage between each pair of conductors should measure the same, but the voltages will be 120 degrees out of phase.



e) If there are three hot conductors and a grounded neutral conductor, single phase power is also available between two or three of the hot conductors and the neutral. This is a 4-wire three-phase system.

Three-Phase Electric Power

Three-phase electric power is a common method of alternating-current electric power generation, transmission, and distribution. It is a type of polyphase system and is the most common method used by electrical grids worldwide to transfer power. It is also used to power large motors and other heavy loads. A three-phase system is usually more economical than an equivalent single-phase or two-phase system at the same voltage because it uses less conductor material to transmit electrical power. The three-phase system was independently invented by Galileo Ferraris, Mikhail Dolivo-Dobrovolsky and Nikola Tesla in the late 1880s.

In a three-phase system, three circuit conductors carry three alternating currents (of the same frequency) which reach their instantaneous peak values at one third of a cycle from each other. Taking one current as the reference, the other two currents are delayed in time by one third and two thirds of one cycle of the electric current. This delay between phases has the effect of giving constant power transfer over each cycle of the current and also makes it possible to produce a rotating magnetic field in an electric motor.

Three-phase systems may have a neutral wire. A neutral wire allows the three-phase system to use a higher voltage while still supporting lower-voltage single-phase loads. In high-voltage distribution situations, it is common not to have a neutral wire as the loads can simply be connected between phases (phase-phase connection).
Three-phase has properties that make it very desirable in electric power systems:

- The phase currents tend to cancel out one another, summing to zero in the case of a linear balanced load. This makes it possible to reduce the size of the neutral conductor because it carries little to no current; all the phase conductors carry the same current and so can be the same size, for a balanced load.
- Power transfer into a linear balanced load is constant, which helps to reduce generator and motor vibrations.
- Three-phase systems can produce a rotating magnetic field with a specified direction and constant magnitude, which simplifies the design of electric motors.

Most household loads are single-phase. In North American residences, three-phase power might feed a multiple-unit apartment block, but each unit is only fed by one of the phases. In lower-density areas, only a single phase might be used for distribution. Some large European appliances may be powered by three-phase power, such as electric stoves and clothes dryers.

Wiring for the three phases is typically identified by color codes which vary by country. Connection of the phases in the right order is required to ensure the intended direction of rotation of three-phase motors. For example, pumps and fans may not work in reverse. Maintaining the identity of phases is required if there is any possibility two sources can be connected at the same time; a direct interconnection between two different phases is a short-circuit.

Generation and Distribution

At the power station, an electrical generator converts mechanical power into a set of three AC electric currents, one from each coil (or winding) of the generator. The windings are arranged such that the currents vary sinusoidally at the same frequency but with the peaks and troughs of their wave forms offset to provide three complementary currents with a phase separation of one-third cycle (120° or $2\pi/3$ radians). The generator frequency is typically 50 or 60 Hz, varying by country.

Transformer Connections

A "delta" connected transformer winding is connected between phases of a three-phase system. A "wye" ("star") transformer connects each winding from a phase wire to a common neutral point.

In an "open delta" or "V" system, only two sets of transformers are used. A closed delta system can operate as an open delta if one of the transformers has failed or needs to be removed. In open delta, each transformer must carry current for its respective phases as well as current for the third phase, therefore capacity is reduced to 87%. With one of three transformers missing and the remaining two at 87% efficiency, the capacity is 58% ((2/3) × 87%).

Where a delta-fed system must be grounded for protection from surge voltages, a grounding transformer (usually a zigzag transformer) may be connected to allow ground fault currents to return from any phase to ground. Another variation is a "corner grounded" delta system, which is a closed delta that is grounded at one of the junctions of transformers.

Three-Wire and Four-Wire Circuits

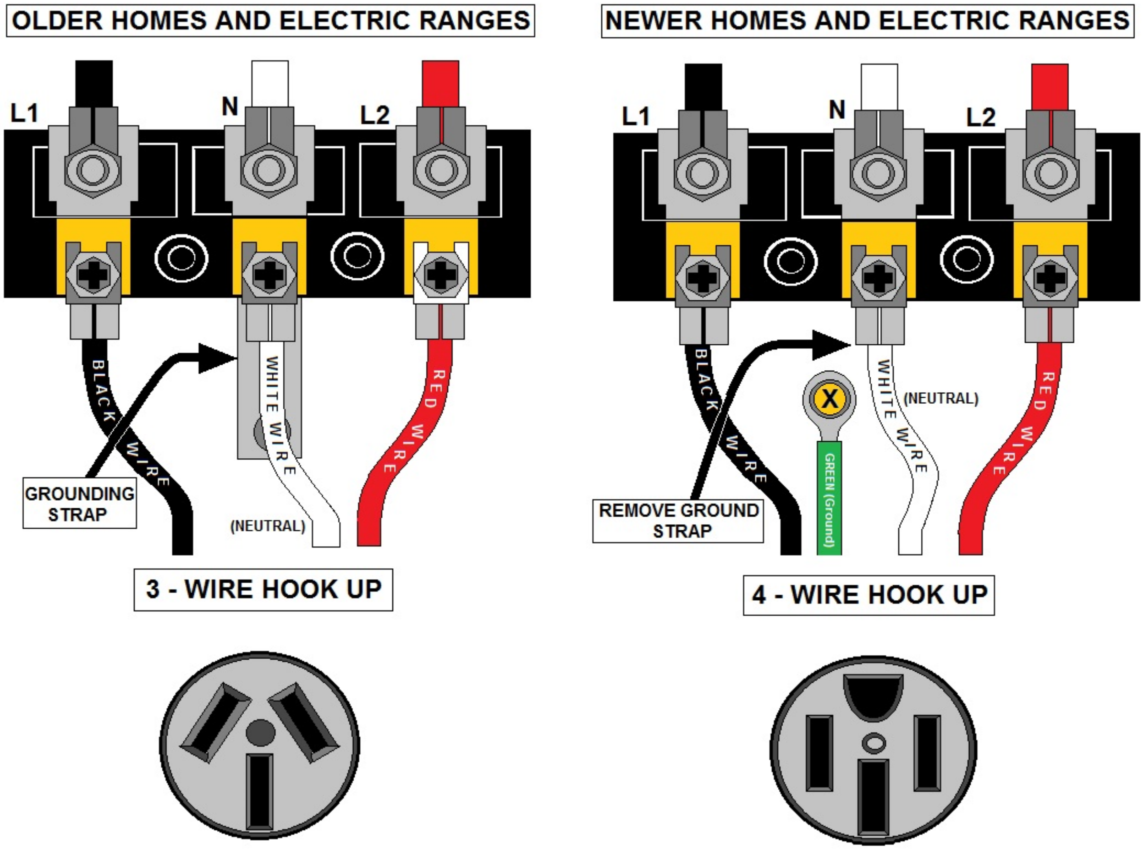
There are two basic three-phase configurations: delta and wye (star). Either type can be wired for three or four wires. The fourth wire, if present, is provided as a neutral. The '3-wire' and '4-wire' designations do not count the ground wire used on many transmission lines which is solely for fault protection and does not carry current under non-fault conditions.

A four-wire system with symmetrical voltages between phase and neutral is obtained when the neutral is connected to the "common star point" of an all supply windings. All three phases will have the same magnitude of voltages to the neutral in such a system. Other non-symmetrical systems have been used. In a high-leg delta system, one winding of a delta transformer feeding the system is center-tapped and connected to neutral. This setup produces three voltages. If the voltage between center tap and the two adjacent phases is 100%, the voltage across any two phases is 200% and neutral to "high leg" is ≈ 173%.

Three-wire distribution systems need one less conductor and help redistribute unbalanced loading during transformation going back to the generation source.

The four-wire wye system is used when ground referenced voltages or the flexibility of more voltage selections are required. Faults on one phase to ground will cause a protection event (fuse or breaker open) locally and not involve other phases or other connected equipment. An example of application is a local distribution in Europe, where each customer is fed a phase and a neutral. When a set of customers sharing the neutral draw unequal currents, the common neutral wire carries a current as a result of the imbalance. Electrical engineers try to design the system so the loads are balanced as much as possible. By distributing a large number of houses over all three phases, on average a nearly balanced load is seen at the point of supply.

In a *three-phase, four-wire, delta* (high-leg delta) system, the neutral is a center tap in one of the delta phase supply windings. This can also be supplied by two single-phase transformers in a *V* formation (open delta).



THREE VERSUS FOUR WIRE CIRCUIT CONNECTIONS

Three-Phase Power Circuits

Example: The voltage on the primary of a 15-to-1 step-down transformer is 7200 volts. What is the voltage on the load?

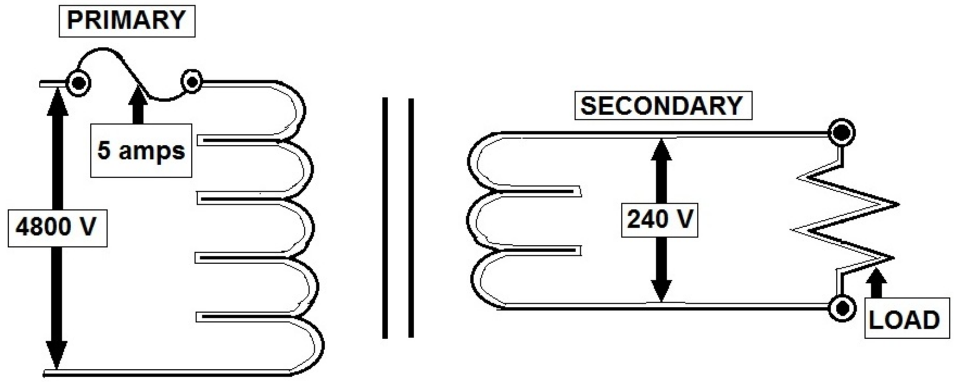
If the load draws 30 amperes, how much current is in the primary, and how many KVA are delivered to the load?

The voltage delivered to the load is 7200/15 = 480 volts.

The current in the primary is 30/15 = 2 amperes.

The KVA delivered to the load is nearly 2 x 7200 = 30 x 480 = 14.4 KVA.

If we assumed an efficiency of less than 1OO% current and KV A in the primary would be somewhat higher.



Practice Exercise A
A transformer intended to step 4800 volts down to 240 has a fuse in the input line to the primary that will blew at 5 amperes.

A. What is the secondary to primary turns ratio? _______

B. What IS the maximum current that can be supplied by the secondary? _______

C. What is the maximum KVA output? _______

Practice Exercise B
A delta-wye transformer produces *120* volts from any line to neutral. The line- to-line primary voltage is *2400.* Calculate:

A. The turns ratio. _______

B. Primary *Winding* current if secondary line current is 40 amperes. _______

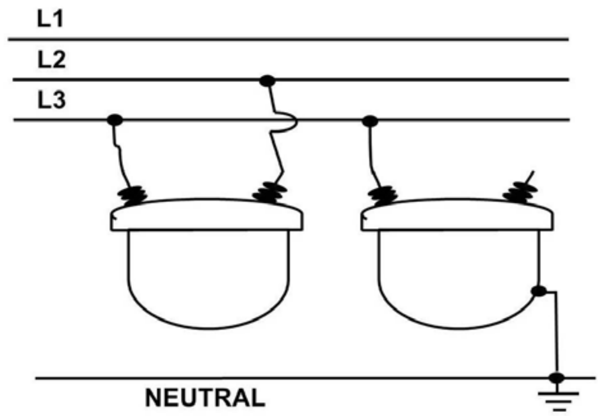
C. Secondary line-to-line voltage. _______

D. Primary line current if secondary line current is 40 amperes. _______

Transformer Connections for Single-Phase Power

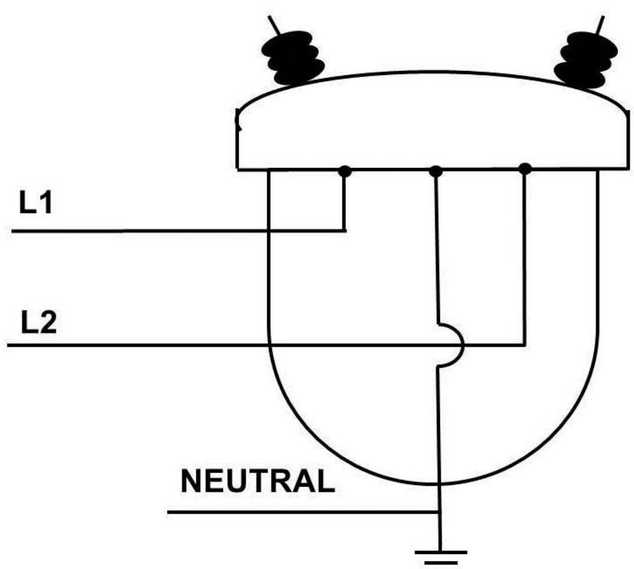
When connecting any transformer to power lines, always be sure that:

- the turns ratio will give -the desired secondary voltage.
- the voltage rating of the transformer primary is not exceeded.
- the KVA rating of the transformer will not be exceeded.



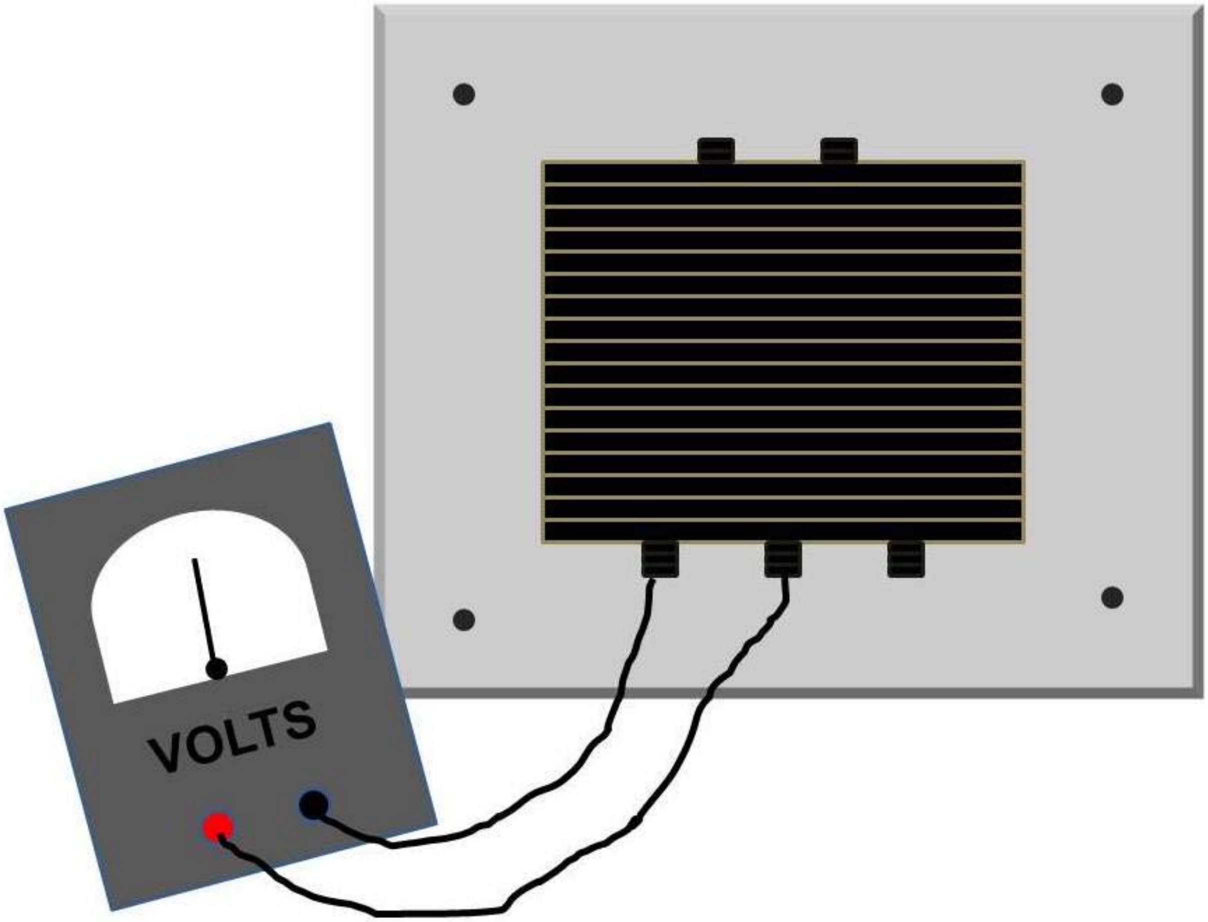
Primary. Single-phase transformers with two primary terminals or leads insulated for high voltage may be connected between two hot conductors or between a hot conductor and neutral.

Transformers with only one primary terminal insulated for high voltage must be connected between a hot conductor and neutral.



Secondary. If a secondary winding has three terminals, the middle one is probably a center tap on the winding.

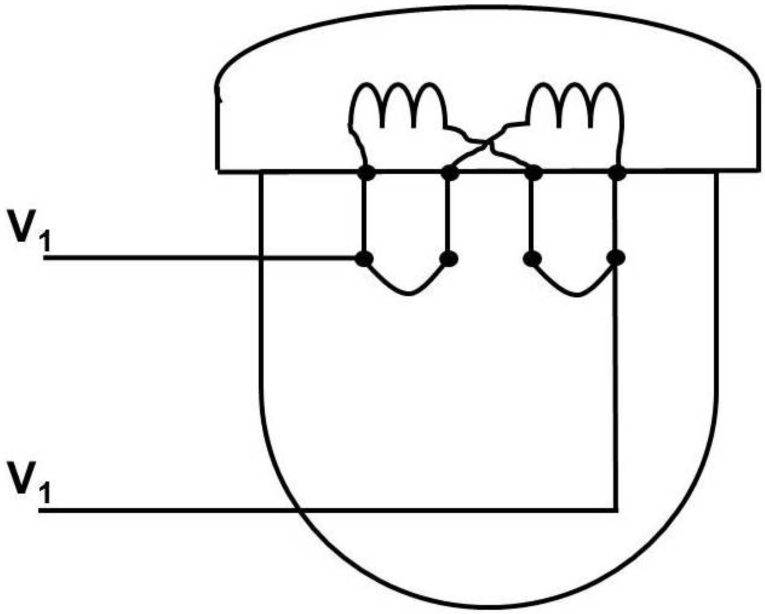
The center tap terminal is usually grounded. If half voltage loads will be supplied as well as full voltage, a grounded neutral conductor is connected to the center terminal.



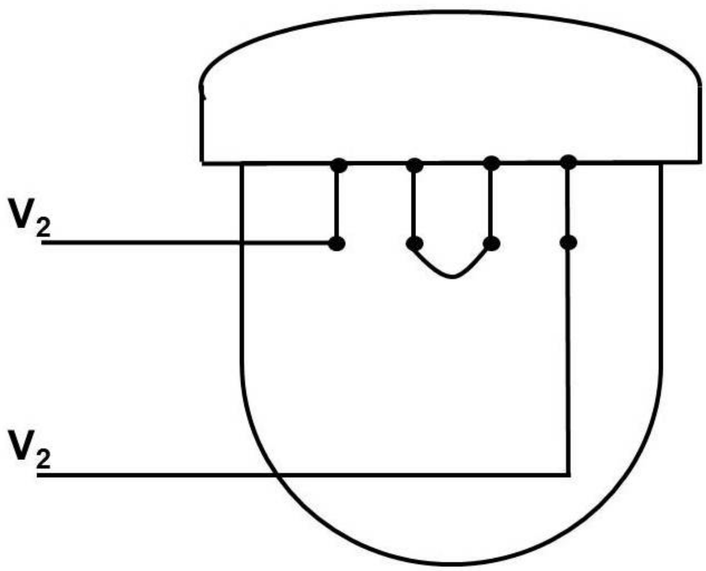
If the secondary has three terminals, and you are not sure which one is the center tap, apply a test voltage to the primary and measure the voltage between secondary terminal pairs. The center tap terminal will read half voltage to either of the others.

$$\frac{V_S}{V_L} = \frac{T_S}{T_P} = \text{TURNS RATIO}$$

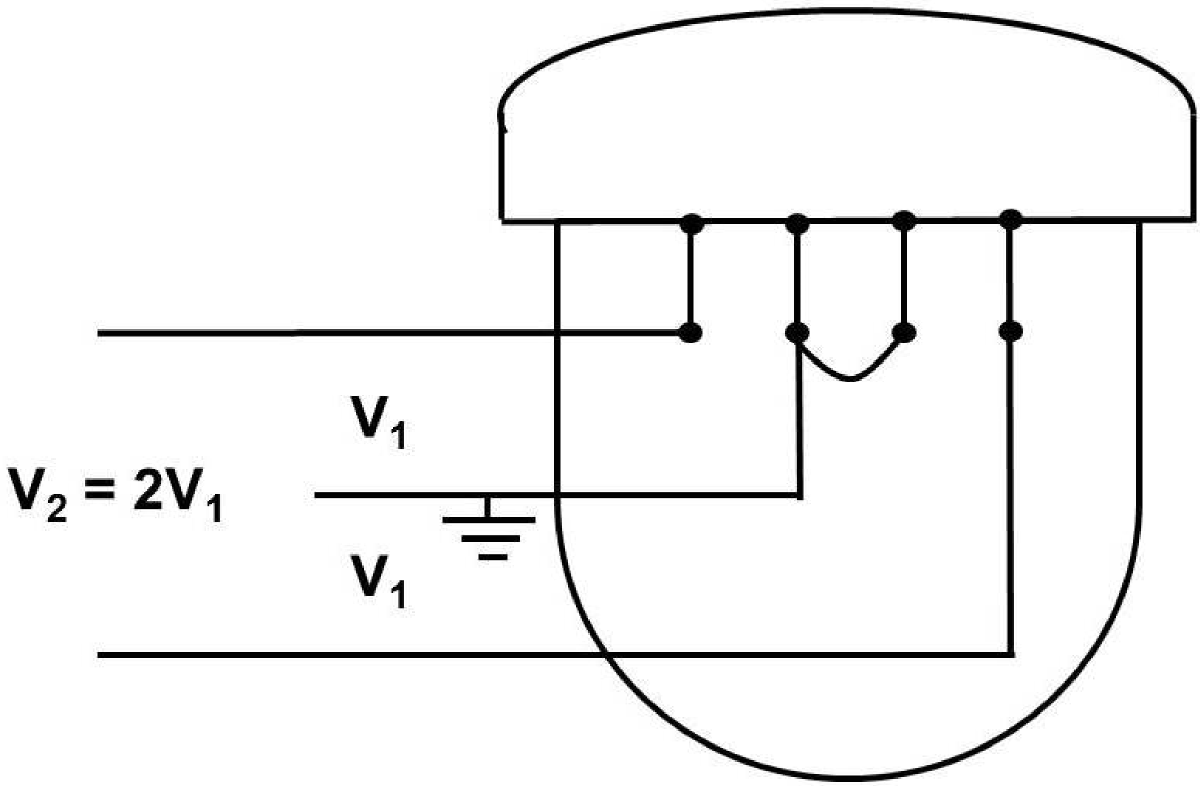
Often there are two separate secondary windings and four terminals or leads.



a) If only half voltage loads will be supplied, connect the secondary windings in parallel.



b) If only full voltage loads will be supplied, connect the windings in series.



c) If both half voltage and full voltage loads will be supplied, connect the windings in series and add a grounded neutral conductor to the junction of the windings.

Transformer terminals are usually arranged so that connecting the center terminals puts the windings in series, and connecting adjacent terminal pairs puts the windings in parallel. If there is any question, however, test the transformer:

First: Identify the windings with an ohmmeter. If two terminals or leads are connected internally through a winding, the resistance reading between them will be quite low.

DO NOT CONNECT THESE TERMINALS TOGETHER EXTERNALLY.

This would short out the winding.

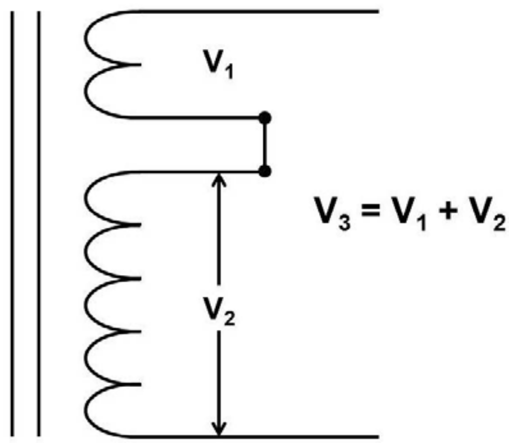
If the reading between two terminals is infinite, they are on separate windings.

Second: Connect one lead or terminal from each secondary winding together. Apply an AC test voltage to the primary and measure the voltage between the remaining two secondary leads or terminals.

If the voltage is zero, the terminals can be connected for parallel operation. If it is twice the voltage across one winding individually, the windings are in series. Reverse one of the secondary winding connections for parallel.

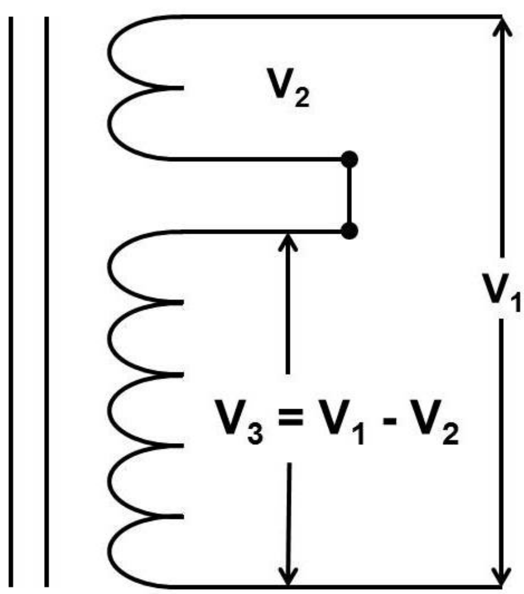
When a load requires a somewhat different voltage from the line voltage available, transformers are sometimes used in a “buck/boost' configuration.

Transformers intended for this kind of service have one main winding intended to take line voltages, and one or more windings with relatively few turns. The windings are connected together, so that the transformer becomes an autotransformer, with one winding.



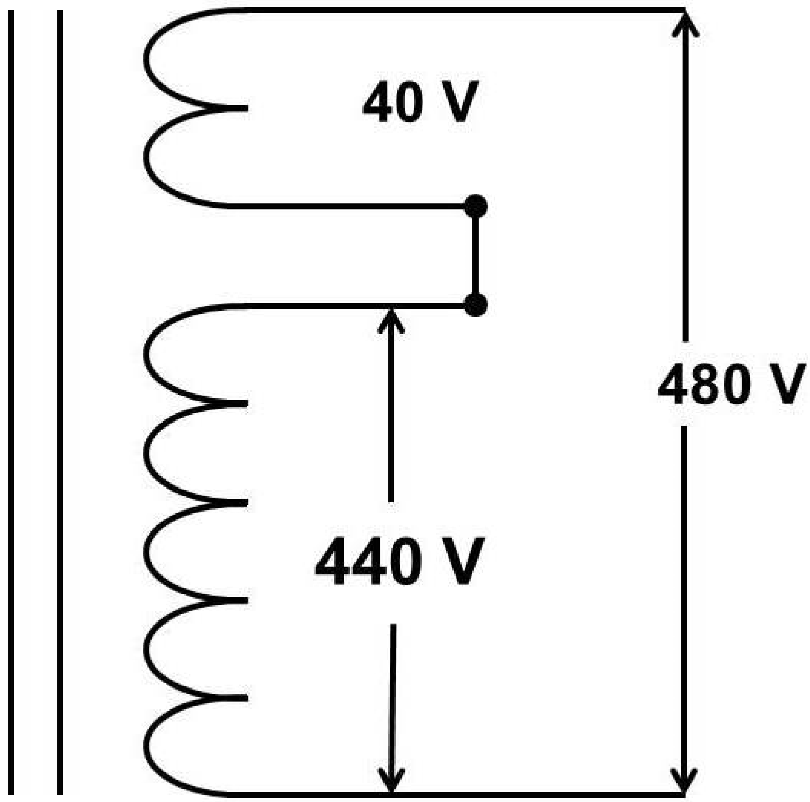
A

A. For a stepped-Up output voltage, the input voltage is applied across the main winding and the output voltage is taken across both windings in series.



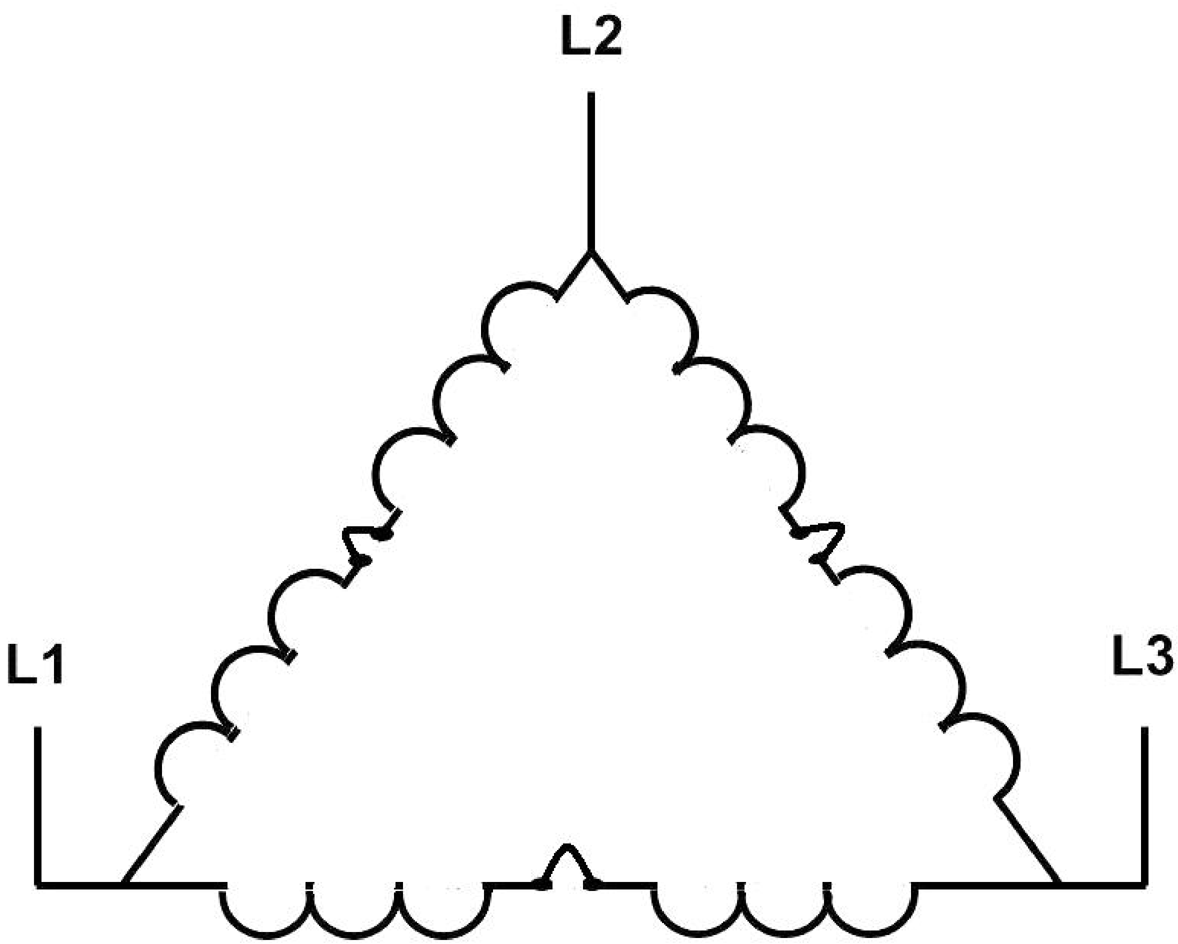
B

B. For a stepped-down voltage, the input voltage is applied across both windings in series, and the output is taken from the main winding only.



If, for example, the local-supply lines provide 440 volts, but a new motor is rated at 480, a buck/boost transformer would be connected as in A.

$$\frac{V_S}{V_L} = \frac{T_S}{T_P} = \text{TURNS RATIO}$$



Practice Exercise

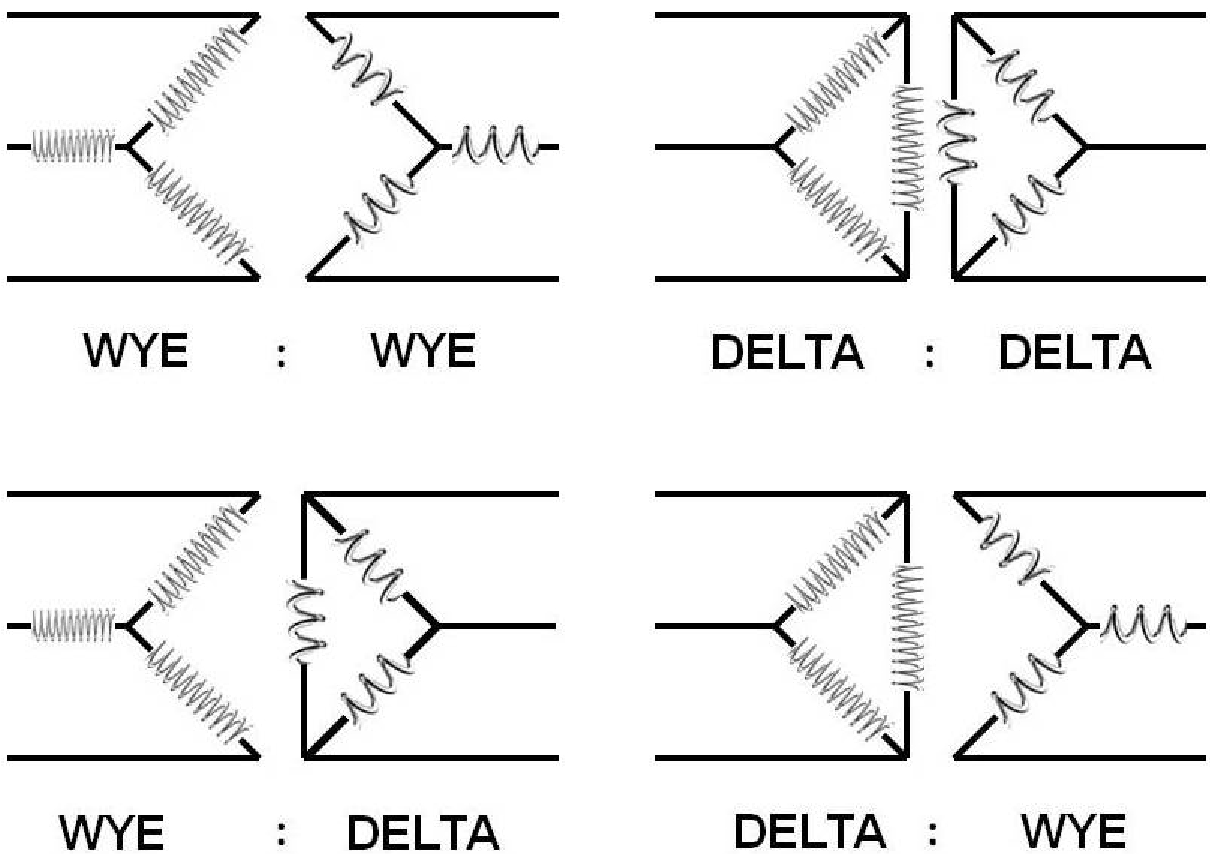
Transformer Connections for Three-Phase Power

Many large power transformer installations provide all three phases, with either a single unit three-phase transformer, or three individual single-phase transformers. In both cases there are three primary windings and three secondary windings. The primary and secondary windings of a transformer system may be connected in either WYE or DELTA.

In a wye connection, one end of each of the windings is connected to a neutral junction. The other end of each winding is connected to a power line.

In a delta connection, the windings are connected to each other in series, .and a hot conductor is connected to each junction.

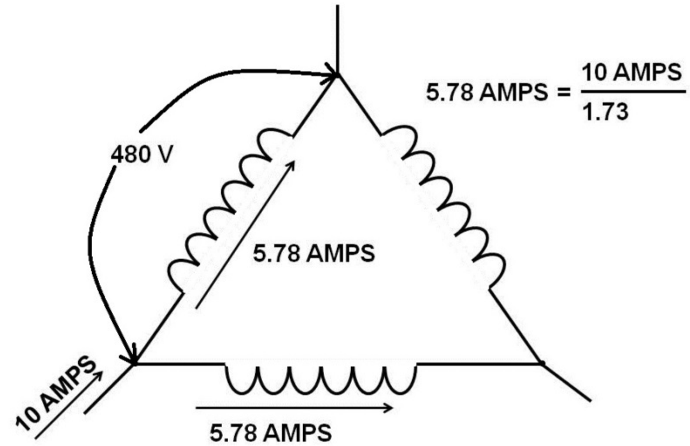
There are four possible three-phase transformer circuit arrangements:

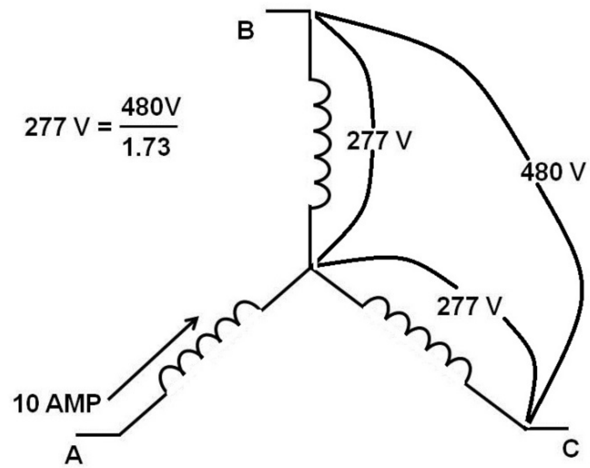


In the delta-delta and wye-wye connections, voltage and current will simply be transformed according to the turns ratio rules.

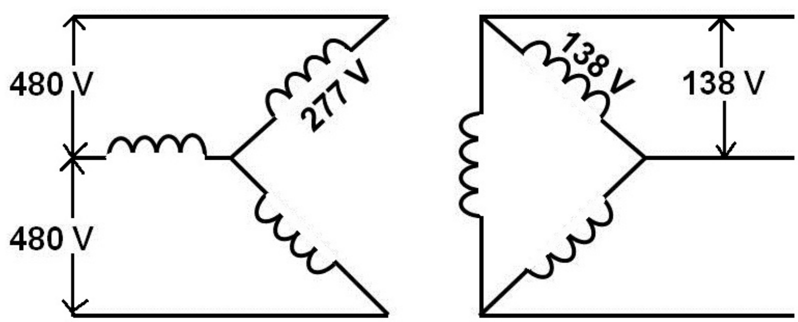
But in delta-wye and wye-delta connections, simply applying the turns ratio will not provide the correct secondary current and voltage values. Additional factors must be taken into account, because current divides in delta, and voltage divides in wye.

a) In a delta connection, voltage across a winding is the same as line-to-line voltage. But line current divides between windings in delta. The current in each winding is line current divided by 1.73.





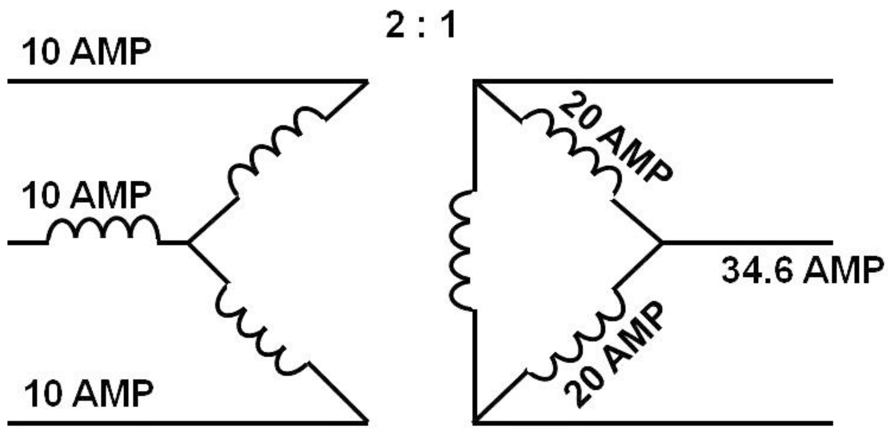
b) In any wye connection, line current and winding current are the same. But line-to-line voltage divides between two windings in wye. The voltage on each winding is line-to-line voltage divided by 1.73.



$$V_S = V_P \div 1.73 \times \text{TURNS RATIO } \frac{V_S}{V_P}$$

$$= 480\text{ V} \div 1.73 \times (1/2)$$

$$= 138\text{ V}$$

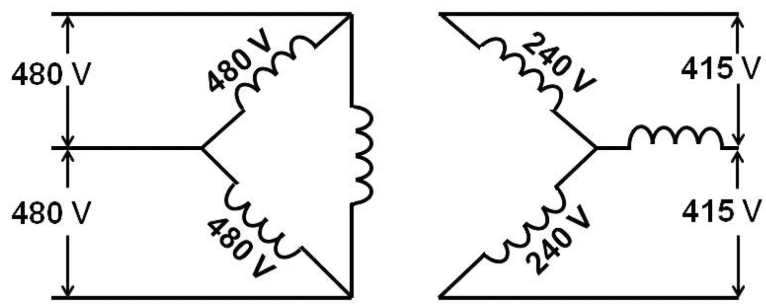


$$I_S = I_P \div \text{TURNS RATIO} \times 1.73$$

$$= 10 \text{ AMP} \div (1/2) \times 1.73$$

$$= 34.6 \text{ AMPS}$$

Wye-delta transformer winding:
Each primary winding will have line-to-line voltage divided by 1.73 on it. This is transformed according to the turns ratio to the secondary winding voltage. Each secondary winding has a powerline connected to each end, so line-to-line voltage out is the same as secondary winding Voltage.

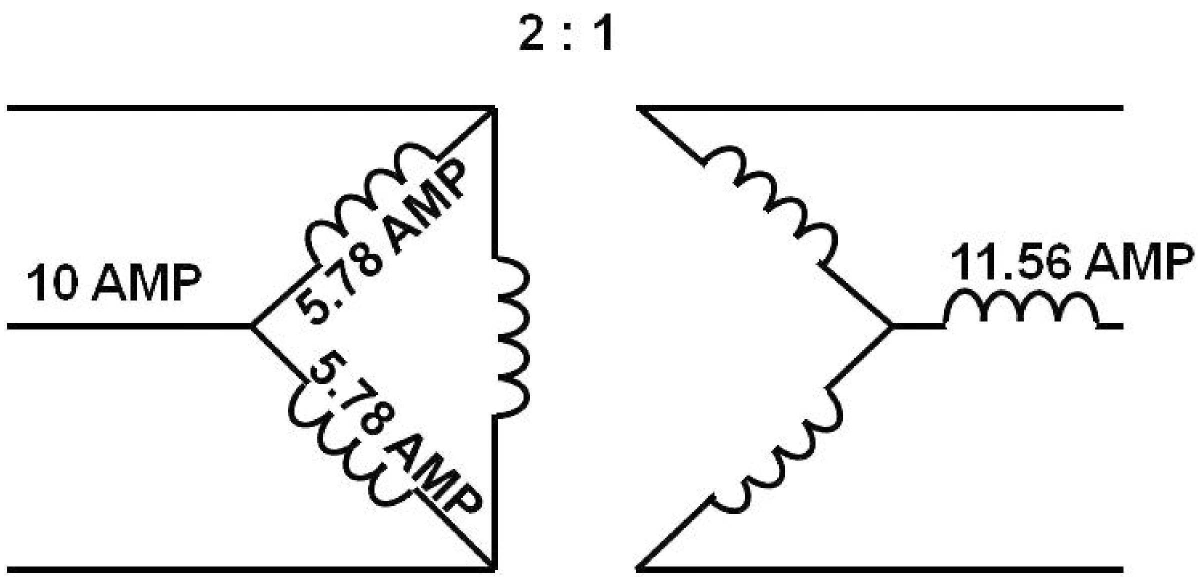


$V_S = V_P$ x **TURNS RATIO X 1.73**

= 480 V x **(1/2 OR .5)** x **1.73**

= 415 V

Each primary winding will have line current in it. This is transformed according to the turns ratio to the secondary winding current. Since the current in each secondary winding is secondary line current divided by 1.73, the secondary line current is secondary winding current times 1.73.



$$I_S = I_P \div 1.73 \div \text{TURNS RATIO}$$

$$= 10 \text{ AMP} \div (1/2 \text{ OR } .5) \div 1.73$$

$$= 11.5 \text{ AMPS}$$

In a delta-wye transformer:
Line-to-line voltage across each primary winding is transformed according to the turns ratio to each secondary winding.

Since the secondary winding voltage is line-to-line voltage divided by 1.73, the line-to-line voltage out is secondary winding voltage times 1.73.

Primary winding current is line current divided by 1.73. Winding current is transformed according to the turns ratio to secondary winding current. Since each secondary winding feeds one power line, current out is secondary winding current.

Practice Exercise

A delta-wye transformer produces 120 volts from any line to neutral. The line- to-line primary voltage is 2400. Calculate:

A. The turns ratio.

B. Primary winding current if secondary line current is 40 amperes.

C. Secondary line-to-line voltage.

D. Primary line current if secondary line current is 40 amperes.

Identifying and Connecting Leads or Terminals

1. Three-phase power from a single unit three-phase transformer:
Three-phase transformers will have at least three primary terminals and three secondary terminals.

Uninsulated fourth terminals on either the primary or secondary side are the neutral junction of a wye connection. If there are no fourth terminals, the internal connection is probably delta.

One high-voltage conductor is connected to each primary terminal, and one low-voltage conductor is connected to each secondary terminal.

Fourth terminals are usually grounded, and connected to their respective neutral conductors.

The only possible problem is that phase sequence may be reversed.

The phases of a three-phase system are usually labelled A, B, and C corresponding to source lines L 1, L2, L3, and load lines T1, T2, T3. Each phase reaches a voltage peak at a different time. In normal sequence: A peaks first, followed by B, and followed by C.

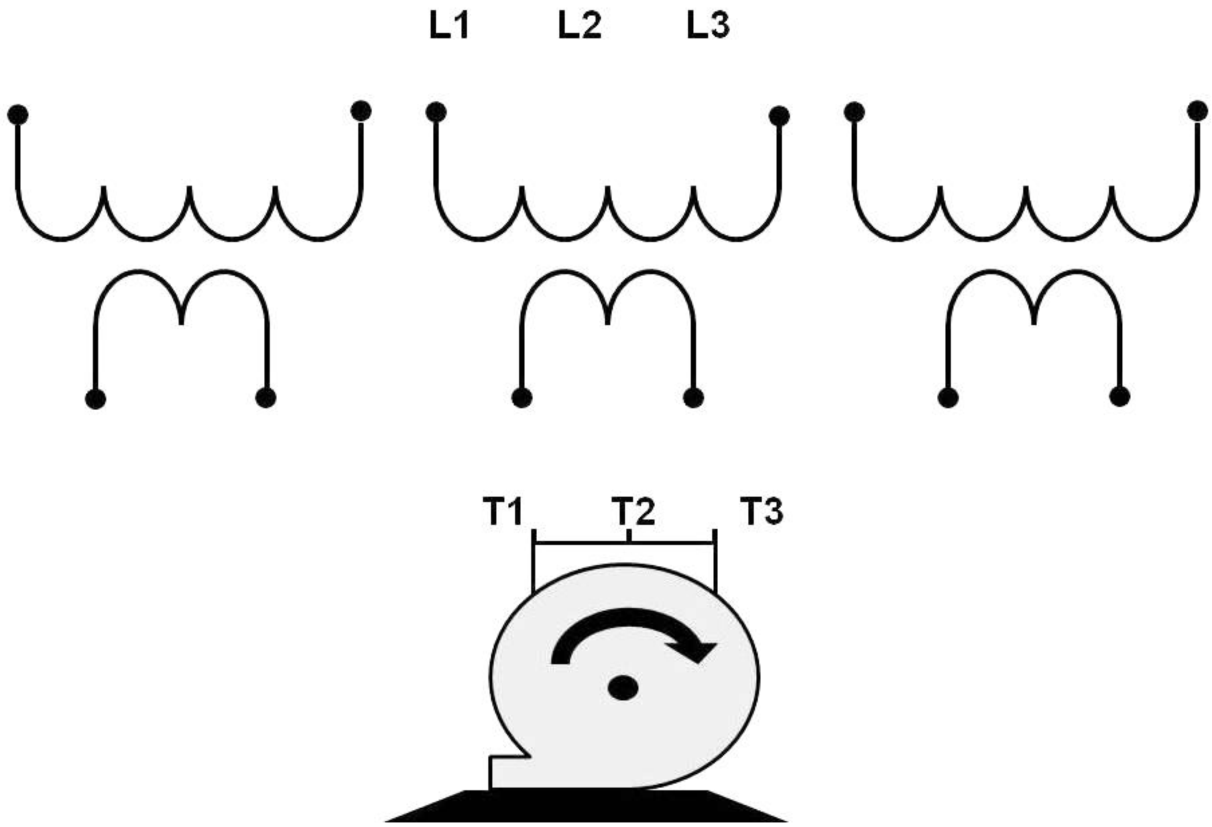
Voltages and power distribution systems that may be encountered in:

120/240	1 phase 3 wire
120/208	3 phase 4 wire "Y"
120/208	3 phase 3 wire "D"
277/480	Phase to ground/phase to phase on 480 volt 3 phase system"
347/600	Phase to ground/phase to phase on 600 volt 3 phase system"

If any two primary or secondary leads are reversed, either at the transformer or at the motor, the effect will be that C will peak before B, and 8 before A. Motors will run backwards.

If you are unsure of proper phase connections, connect the primary and secondary conductors in any order. However, before applying power, check the rotation direction of one motor where reverse rotation will not cause any problems. Uncouple the motor first, that is if necessary. It the motor turns in the correct direction, all the other motors powered by the same transformer will also turn in the correct direction.

If the motor runs backwards, turn off the power and swap the two primary lines or any secondary lines. By convention, phases A and C are swapped to reverse motor rotation direction.



Practice Exercise

Three-Phase Power from Three Single-Phase Transformers

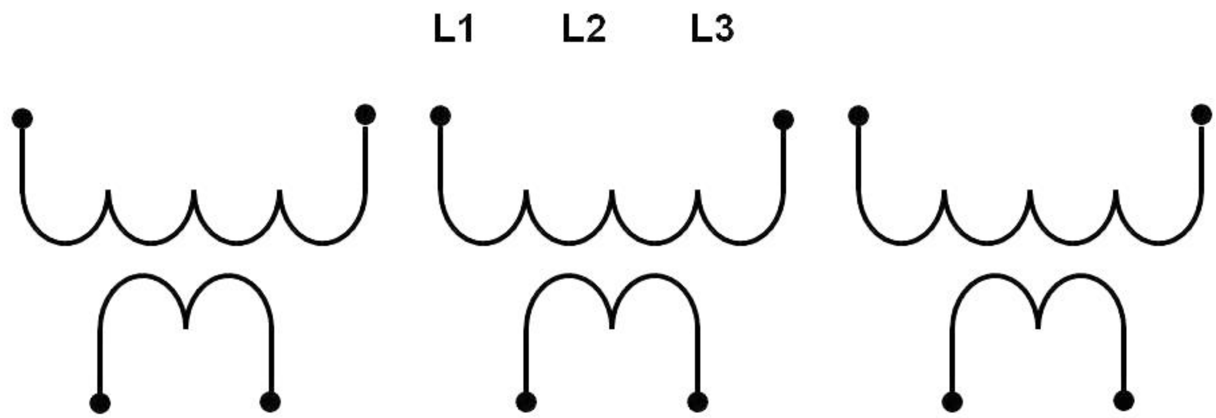
Just as in a single unit 3-phase transformer, there are three primary and three secondary windings. There is more chance for misconnection, however, because secondary windings are often divided into two parts, and all the winding terminals or leads are available for connection.

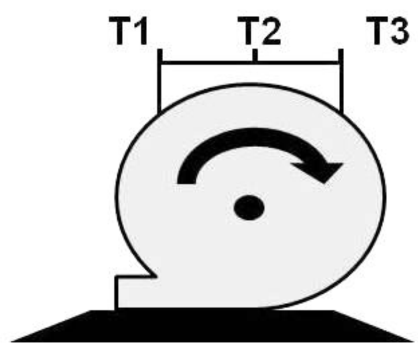
The polarity of the connections, as well as the phase sequence, must be right.

Polarity refers to the relationship between primary and secondary voltages.

If the polarity of anyone winding is reversed, one phase voltage will be reversed, quickly tripping breakers~ blowing fuses, or damaging motors.

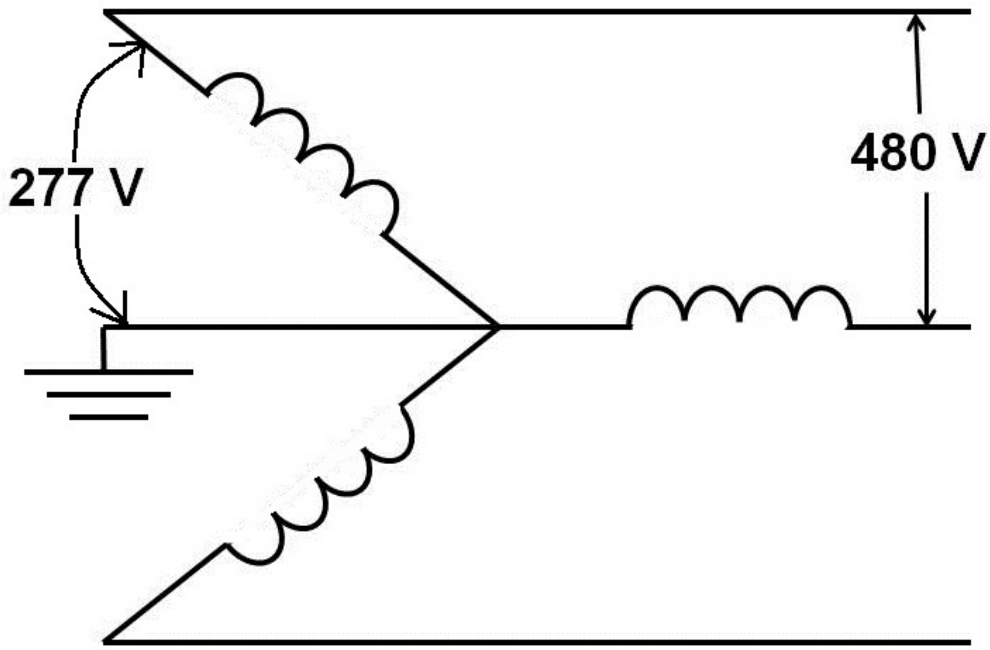
Usually there will be no polarity problem as long as L1, L2, and L3 are connected the same way to the primary and secondary terminals of similar transformers.





Connect the three transformers in wye-wye, and connect the motor so that it runs in the forward direction, and with no reversed phase polarity.

Grounding Three-Phase Systems



Neutral junctions of wye' connected transformer windings, both primary and secondary, are usually grounded. As a result, the voltages to ground on power lines in a wye system will be equal to line-to-line voltage divided by 1.73. Line-to-line voltage will be equal to line-to-ground voltage times 1.73. If voltages are different from this on any power line, something is wrong.

Delta Systems
Delta systems do not have a convenient grounding point Sometimes, they are left ungrounded. In this case, voltage to ground measurements on the three power lines mayor may not be meaningful. If a low resistance voltmeter is used, the act of measuring the voltage grounds the phase, and voltage may read very low or zero. If a high resistance voltmeter is used, the voltage to ground on phase lines should read approximately equal to line-to-line voltage divided by 1.73, as in wye systems.

If voltage is zero or very row on one phase, and the same as line-to-line voltage on the other two, there is a short to ground on the low voltage phase. Equipment operation will not be affected by one short to ground. But if another short to ground developed, dangerous currents would flow between the shorts.

It is important to detect and repair shorts to ground promptly.

Corner grounded delta systems are permanently tied to ground on one phase.

Voltage on the grounded phase will naturally be zero, and voltage to ground on the other two phases will equal line-to-line voltage.

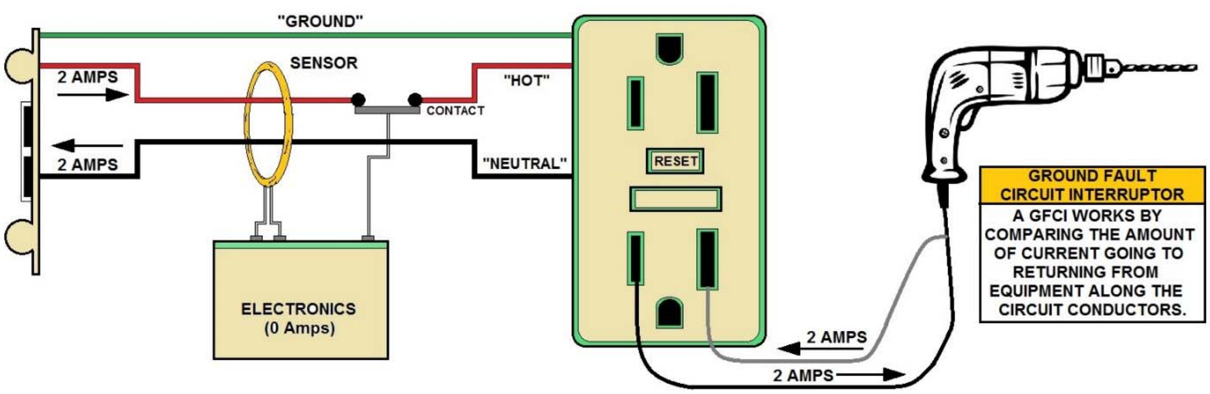
Whether or not conductors or transformers are grounded, all equipment frames, housings, conduits, cable trays, busways, and exposed parts should be grounded for safety.

Circuit-Interrupters

AFCIs (arc-fault circuit-interrupters)
When an electrical switch is opened or closed, an arc, or discharge of electricity across a circuit, occurs. Unintentional arcs can occur at loose connections or where wires or cords have been damaged. Such arcs can lead to high temperatures and sparking, possibly igniting combustibles. AFCIs (arc-fault circuit-interrupters) protect against fire by continuously monitoring the electrical current in a circuit and shutting off the circuit when unintended arcing occurs. These devices are designed to discriminate between unintended arcing and the type of arcing that occurs when a switch is operated.

GFCIs (ground-fault circuit-interrupters)

A ground-fault is an unintentional electrical path between a source of electrical current and a grounded surface. Electrical shock can occur if a person comes into contact with an energized part. GFCIs (ground-fault circuit-interrupters) can greatly reduce the risk of shock by immediately shutting off an electrical circuit when that circuit represents a shock hazard (i.e., a person comes in contact with a faulty appliance together with a grounded surface). GFCIs can be installed in a circuit breaker panel board or directly in a receptacle outlet.



EXAMPLE OF A GROUND FAULT CIRCUIT INTERRUPTOR (GFCI)

Facts and Figures

- **AFCI** installation is required by the *National Electrical Code® (NEC)* in bedrooms of new residential construction (effective as of January 1, 2002). Bedrooms were selected as the first area in which to implement this requirement because of a history of fires there.
- **GFCI** installation is required by the *NEC* for receptacles in kitchens, bathrooms, outdoor areas, basements and garages in new residential construction because of a history of shock hazards in these areas.

What are Arc-Fault Circuit Interrupters (AFCIs)?
The 2008 National Electrical Code® (NEC®) requirement for AFCI protection considerably expands this fire prevention technology to the majority of circuits installed in new and renovated homes. The type of AFCI currently available commercially is a next-generation circuit breaker that not only provides the conventional safety functions, but its advanced design also rapidly detects potentially dangerous arcs and disconnects power in the circuit before a fire can start. Fire safety officials throughout the United States endorse AFCIs as a significant step forward in electrical fire safety.

Why should they be installed in homes?
AFCIs will save lives and make homes safer. According to the U.S. Fire Administration, each year home electrical problems cause about 70,000 fires, resulting in 485 deaths and $868 million in property loss.

Why mandate AFCIs for newer homes when statistics show the majority of problems have occurred in older homes?
Fire safety officials recommend the use of AFCIs in all dwellings. While it is true that fire statistics in many cases are derived from older dwellings, damage to appliance cords or to wires hidden in a wall can occur regardless of the home's age. In addition, incorrectly performed electrical installations can occur in both new and old homes. As technology evolves and the NEC is revised, the enhanced level of safety is typically required only in new construction that is subject to the latest adopted edition. Homes wired per the 2008 NEC will have the majority of their circuits protect by AFCIs for the life of the electrical system.
How do you know AFCIs will prevent fires and save lives?
Since 1999, AFCIs have been thoroughly field-tested. Underwriters Laboratories, the National Association of State Fire Marshals (NASFM), the U.S. Consumer Product Safety Commission, and many other experts have found AFCIs to be reliable and effective. By eliminating a significant source of electrically related fires, future statistics will demonstrate a reduction in fires of electrical origin.

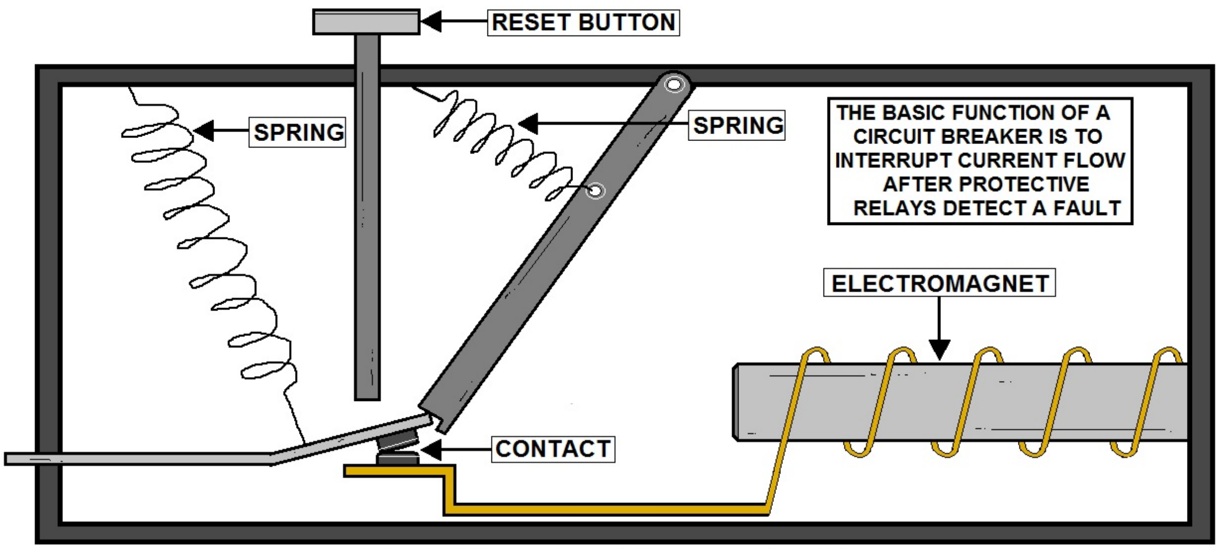
Are AFCIs expensive?
The cost of the enhanced protection is directly related to the size of the dwelling and the number of circuits installed. Current retail prices of AFCI-type circuit breakers at several national building supply chains are in the range of $35 to $40 per unit. Even for larger homes with more circuits, the cost increase is insignificant compared to the total cost of the home, particularly when the increased level of safety is factored.

Do AFCIs interfere with smoke alarms and appliances, and trip unnecessarily?
AFCIs do not interfere with power supply reliability. These state-of-the-art devices identify problems that current circuit breakers are not designed to protect against, which can result in what appears to be an unexplained circuit breaker trip. By actually identifying these problems, residents are safer.

- U.S. fire departments responded to an estimated annual average of 47,820 reported home structure fires involving electrical failure or malfunction in 2007-2011. These fires resulted in 455 civilian deaths, 1,518 civilian injuries and $1.5 billion in direct property damage.
- Replace or repair damaged or loose electrical cords.
- Avoid running extension cords across doorways or under carpets.
- In homes with small children, make sure your home has tamper-resistant (TR) receptacles.
- Consider having additional circuits or outlets added by a qualified electrician so you do not have to use extension cords.
- Follow the manufacturer's instructions for plugging an appliance into a receptacle outlet.
- Avoid overloading outlets. Plug only one high-wattage appliance into each receptacle outlet at a time.
- If outlets or switches feel warm, frequent problems with blowing fuses or tripping circuits, or flickering or dimming lights, call a qualified electrician.

- Place lamps on level surfaces, away from things that can burn and use bulbs that match the lamp's recommended wattage.
- Make sure your home has ground fault circuit interrupters (GFCIs) in the kitchen bathroom(s), laundry, basement, and outdoor areas.
- Arc-fault circuit interrupters (AFCIs) should be installed in your home to protect electrical outlets.

  Protective devices capable of responding to overloads and short circuit, such as circuit breakers, have been available for a number of years. Newer technologies now provide enhanced protection from arcing or ground-faults, which may prevent fires or shock.



CIRCUIT BREAKER EXAMPLE

Section 9 – Transformers Post Quiz

1. Occasionally the advantages of three-phase motors make it worthwhile to convert single-phase power to?

2. A static phase converter method does not work when sensitive circuitry is involved such as CNC devices or in induction and?

3. A three-phase generator can be driven by a?

4. The usage of the main transformer method separated it from another common method, the static converter, as both methods have no moving parts, which separates them from the?

5. Another method often attempted is with a device referred to as?

6. Some devices are made which create an imitation three-phase from?

7. Which term works by converting the supply voltage to DC and then converting the DC to a suitable three-phase source for the motor.

Alternatives to Three-Phase

8. Which term is used when three-phase power is not available and allows double the normal utilization voltage to be supplied for high-power loads?

9. According to the text, loads that connect each phase to neutral, assuming the load is the same power draw, the two-wire system has a neutral current which is greater than neutral current in?

10. High-phase-order transmission lines may allow transfer of more power through a given transmission line right-of-way without the expense of a high-voltage direct current converter at each end of the line.
A. True B. False

Section 9 – Transformers Post Quiz

1. Three-phase
2. Rectifier-type loads
3. Single-phase motor
4. Rotary converters
5. A static phase converter
6. Three-wire single-phase
7. VFDs
8. Split-phase electric power
9. A three-phase system
10. True

Section 10 – Electrical Motors

Section Focus: You will learn advanced electrical theories and laws. At the end of this section, you will be able to understand and describe electrical motors and their operation. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: In order to understand electrical principles, we first need to explain the various simple forms of electrical currents. Because this area of study is quite large and detailed, we will only focus on electrical motors.

Motor Section

We will now refer to the motor, coupling, and bearings. The power source of the pump is usually an electric motor. The motor is connected by a coupling to the pump shaft. The purpose of the bearings is to hold the shaft firmly in place, yet allow it to rotate. The bearing house supports the bearings and provides a reservoir for the lubricant. An impeller is connected to the shaft. The pump assembly can be a vertical or horizontal set-up; the components for both are basically the same.

Motors

The purpose of this discussion on pump motors is to identify and describe the main types of motors, starters, enclosures and motor controls, as well as to provide you with some basic maintenance and troubleshooting information. Although pumps could be driven by diesel or gasoline engines, pumps driven by electric motors are commonly used in our industry.

There are two general categories of electric motors:

- D-C motors, or direct current
- A-C motors, or alternating current

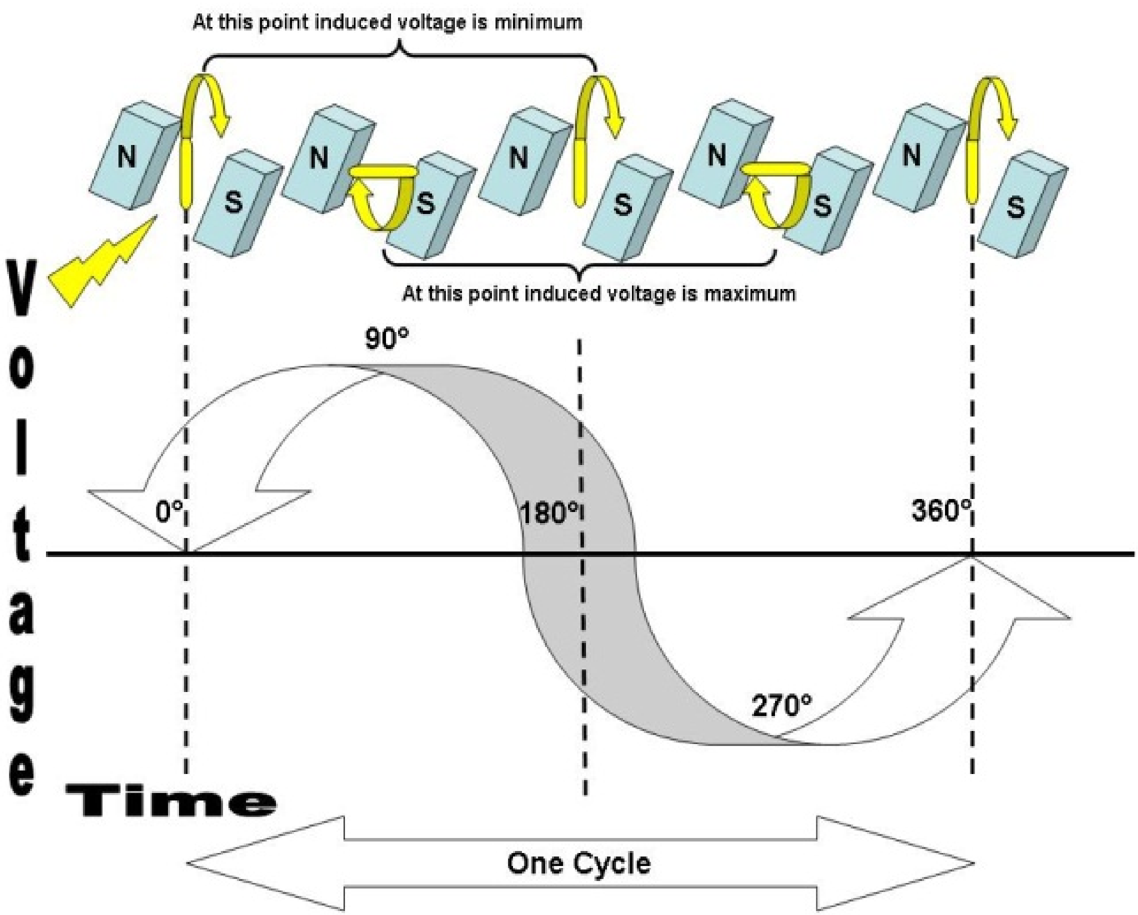
You can expect most motors at facilities to be A-C type.

D-C Motors

The important characteristic of the D-C motor is that its speed will vary with the amount of current used. There are many different kinds of D-C motors, depending on how they are wound and their speed/torque characteristics.

A-C Motors

There are a number of different types of alternating current motors, such as Synchronous, Induction, wound rotor, and squirrel cage. The synchronous type of A-C motor requires complex control equipment, since they use a combination of A-C and D-C. This also means that the synchronous type of A-C motor is used in large horsepower sizes, usually above 250 HP. The induction type motor uses only alternating current. The squirrel cage motor provides a relatively constant speed. The wound rotor type could be used as a variable speed motor.



Define the Following Terms:

Voltage:

EMF:

Power:

Current:

Resistance:

Conductor:

Phase:

Single Phase:

Three Phase:

Hertz:

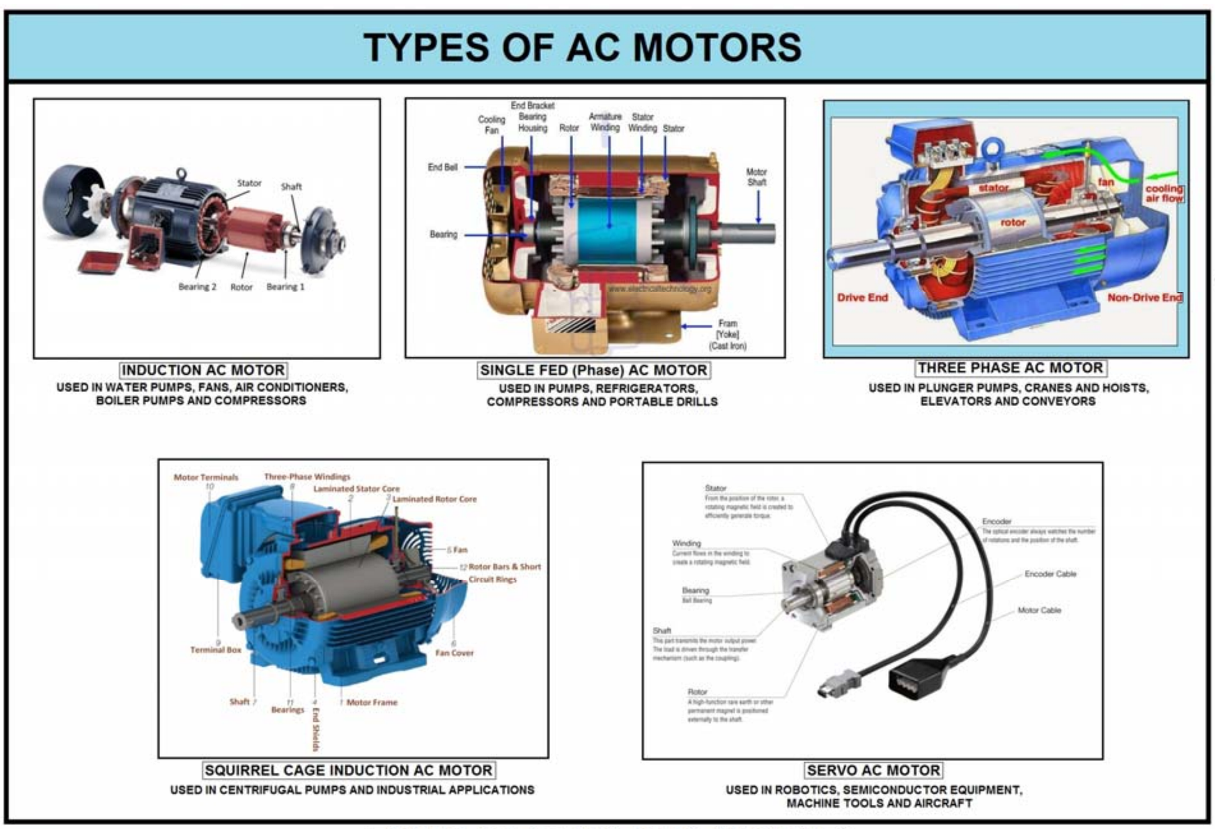
Motor Starters

All electric motors, except very small ones such as chemical feed pumps, are equipped with starters, either full voltage or reduced voltage. This is because motors draw a much higher current when they are starting and gaining speed. The purpose of the reduced voltage starter is to prevent the load from coming on until the amperage is low enough.

How do you think keeping the discharge valve closed on a centrifugal pump could reduce the start-up load?

Motor Enclosures

Depending on the application, motors may need special protection. Some motors are referred to as open motors. They allow air to pass through to remove heat generated when current passes through the windings. Other motors use specific enclosures for special environments or safety protection.



TYPES OF AC MOTORS AND USES

Two Types of Totally Enclosed Motors Commonly Used are:

- **TENV**, or totally enclosed non-ventilated motor
- **TEFC**, or totally enclosed fan cooled motor

Totally enclosed motors include dust-proof, water-proof and explosion-proof motors. An explosion proof enclosure must be provided on any motor where dangerous gases might accumulate.

Motor Controls
All pump motors are provided with some method of control, typically a combination of manual and automatic. Manual pump controls can be located at the central control panel at the pump or at the suction or discharge points of the liquid being pumped.

There are a number of ways in which automatic control of a pump motor can be regulated:

- Pressure and vacuum sensors
- Preset time intervals
- Flow sensors
- Level sensors

Two typical level sensors are the float sensor and the bubble regulator. The float sensor is pear-shaped and hangs in the wet well. As the height increases, the float tilts, and the mercury in the glass tube flows toward the end of the tube that has two wires attached to it. When the mercury covers the wires, it closes the circuit.

A low pressure air supply is allowed to escape from a bubbler pipe in the wet well. The back-pressure on the air supply will vary with the liquid level over the pipe. Sensitive air pressure switches will detect this change and use this information to control pump operation.

Motor Maintenance
Motors should be kept clean, free of moisture, and lubricated properly. Dirt, dust, and grime will plug the ventilating spaces and can actually form an insulating layer over the metal surface of the motor.

What condition would occur if the ventilation becomes blocked?

Moisture

Moisture harms the insulation on the windings to the point where they may no longer provide the required insulation for the voltage applied to the motor. In addition, moisture on windings tend to absorb acid and alkali fumes, causing damage to both insulation and metals. To reduce problems caused by moisture, the most suitable motor enclosure for the existing environment will normally be used. It is recommended to run stand by motors to dry up any condensation which accumulates in the motor.

Motor Lubrication

Friction will cause wear in all moving parts, and lubrication is needed to reduce this friction. It is very important that all your manufacturer's recommended lubrication procedures are strictly followed. You have to be careful not to add too much grease or oil, as this could cause more friction and generate heat.

To grease the motor bearings, this is the usual approach:

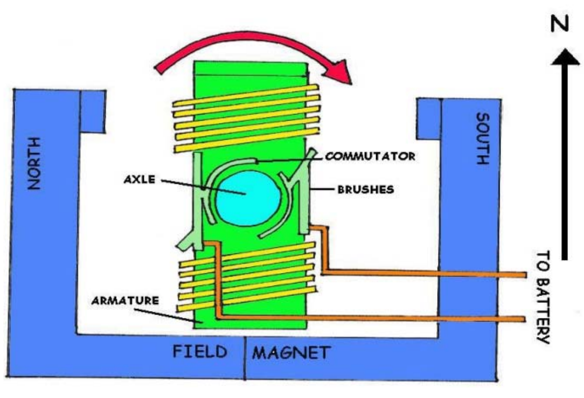
1. Remove the protective plugs and caps from the grease inlet and relief holes.
2. Pump grease in until fresh starts coming from the relief hole.

If fresh grease does not come out of the relief hole, this could mean that the grease has been pumped into the motor windings. The motor must then be taken apart and cleaned by a qualified service representative.

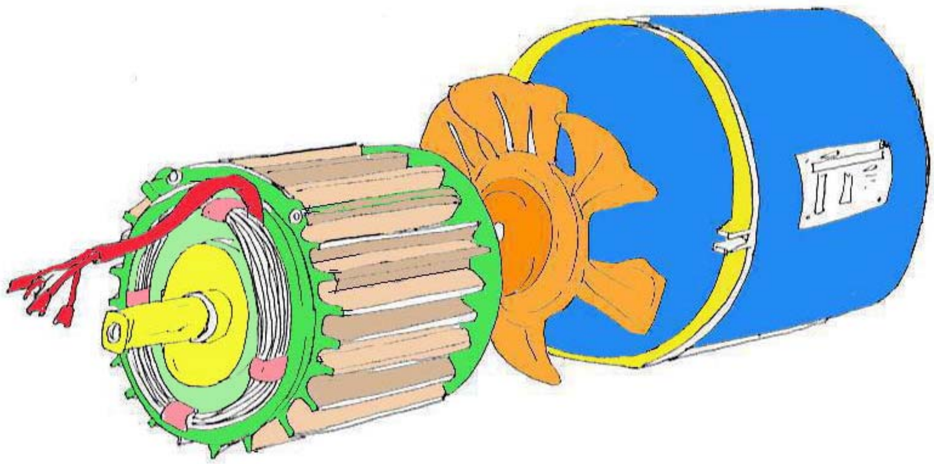
To change the oil in an oil lubricated motor, this is the usual approach:

1. Remove all plugs and let the oil drain.
2. Check for metal shearing.
3. Replace the oil drain.
4. Add new oil until it is up to the oil level plug.
5. Replace the oil level and filter plug.

Never mix oils, since the additives of different oils when combined can cause breakdown of the oil.



Electrical Motor Introduction



The classic division of electric motors has been that of Direct Current (**DC**) types vs. Alternating Current (**AC**) types. This is more a de facto convention, rather than a rigid distinction. For example, many classic DC motors run happily on AC power.

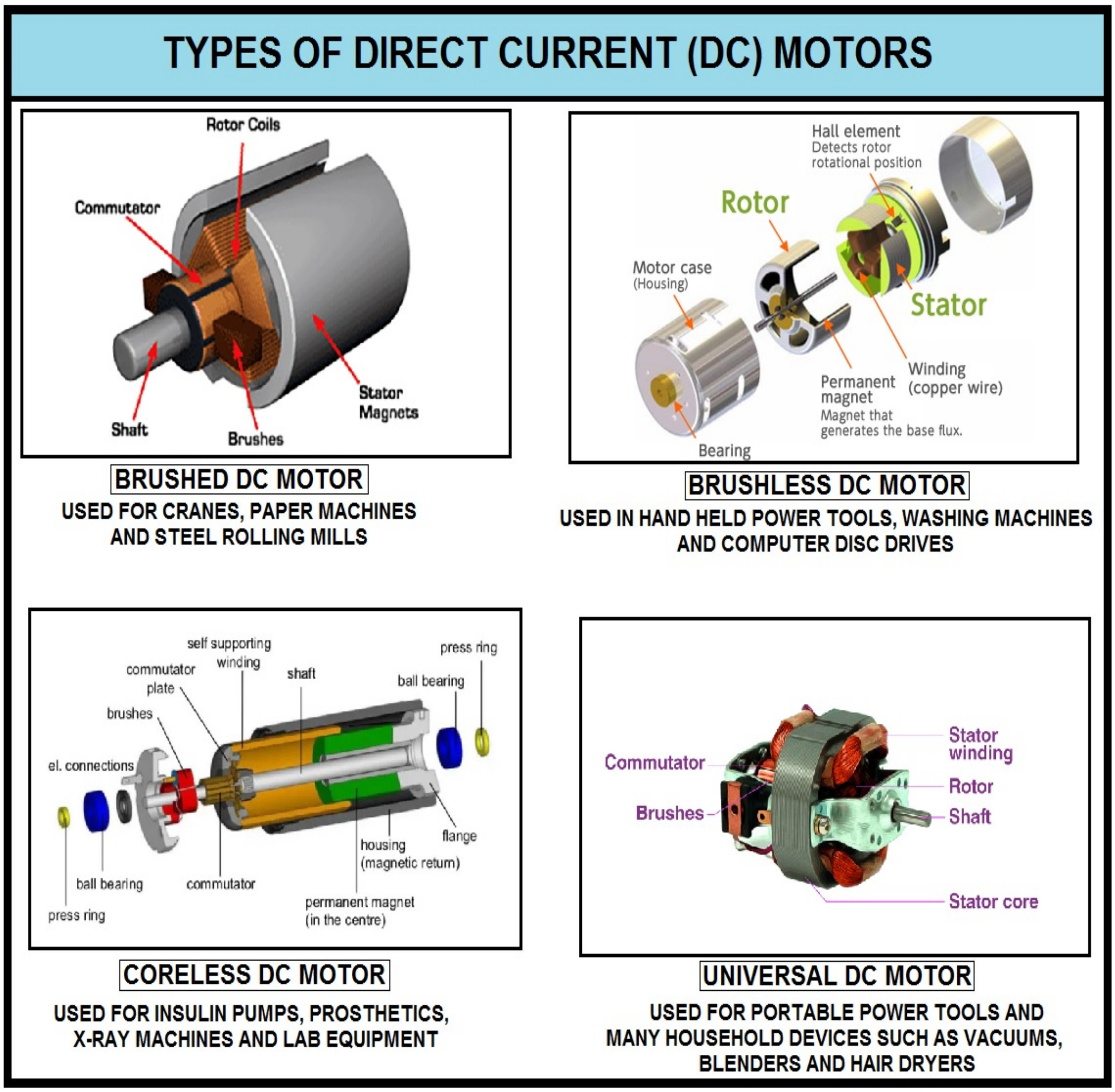
The ongoing trend toward electronic control further muddles the distinction, as modern drivers have moved the commutator out of the motor shell. For this new breed of motor, driver circuits are relied upon to generate sinusoidal AC drive currents, or some approximation of. The two best examples are: the brushless DC motor and the stepping motor, both being polyphase AC motors requiring external electronic control.

There is a clearer distinction between a synchronous motor and asynchronous types. In the synchronous types, the rotor rotates in synchrony with the oscillating field or current (e.g. permanent magnet motors). In contrast, an asynchronous motor is designed to slip; the most ubiquitous example being the common AC induction motor which must slip in order to generate torque.

A DC motor is designed to run on DC electric power. Two examples of pure DC designs are Michael Faraday's homopolar motor (which is uncommon), and the ball bearing motor, which is (so far) a novelty. By far the most common DC motor types are the brushed and brushless types, which use internal and external commutation respectively to create an oscillating AC current from the DC source -- so they are not purely DC machines in a strict sense.

Brushed DC Motors
The classic DC motor design generates an oscillating current in a wound rotor with a split ring commutator, and either a wound or permanent magnet stator. A rotor consists of a coil wound around a rotor which is then powered by any type of battery. Many of the limitations of the classic commutator DC motor are due to the need for brushes to press against the commutator. This creates friction. At higher speeds, brushes have increasing difficulty in maintaining contact. Brushes may bounce off the irregularities in the commutator surface, creating sparks. This limits the maximum speed of the machine.

The current density per unit area of the brushes limits the output of the motor. The imperfect electric contact also causes electrical noise. Brushes eventually wear out and require replacement, and the commutator itself is subject to wear and maintenance. The commutator assembly on a large machine is a costly element, requiring precision assembly of many parts.



TYPES OF DC MOTORS AND USES

Technical Learning College

Brushless DC Motors
Some of the problems of the brushed DC motor are eliminated in the brushless design. In this motor, the mechanical "rotating switch" or commutator/brush gear assembly is replaced by an external electronic switch synchronized to the rotor's position. Brushless motors are typically 85-90% efficient, whereas DC motors with brush gear are typically 75-80% efficient.

Midway between ordinary DC motors and stepper motors lies the realm of the brushless DC motor. Built in a fashion very similar to stepper motors, these often use a permanent magnet external rotor, three phases of driving coils, one or more Hall Effect sensors to sense the position of the rotor, and the associated drive electronics.

The coils are activated one phase after the other by the drive electronics, as cued by the signals from the Hall effect sensors. In effect, they act as three-phase synchronous motors containing their own variable-frequency drive electronics.
Brushless DC motors are commonly used where precise speed control is necessary, as in computer disk drives or in video cassette recorders, the spindles within CD, CD-ROM (etc.) drives, and mechanisms within office products such as fans, laser printers, and photocopiers.

They have several advantages over conventional motors:

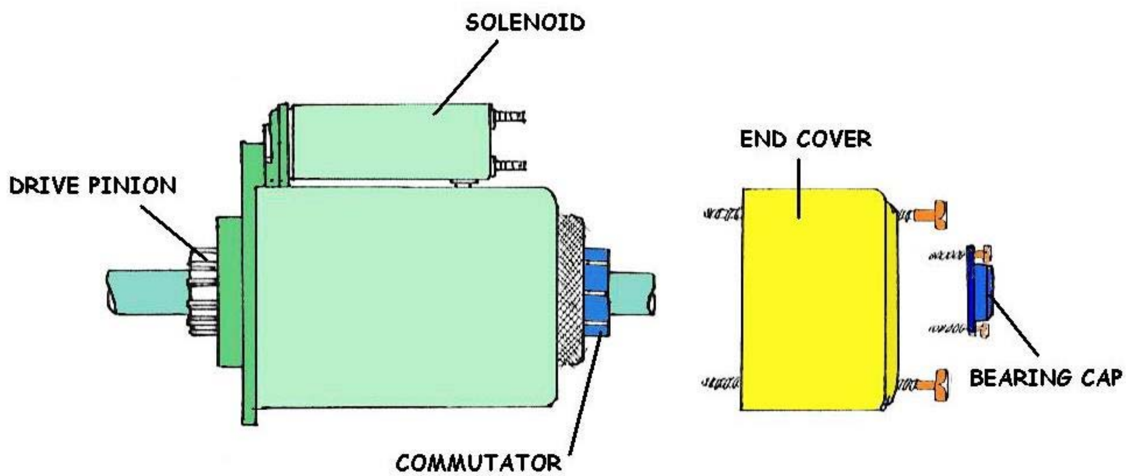
- Compared to AC fans using shaded-pole motors, they are very efficient, running much cooler than the equivalent AC motors. This cool operation leads to much-improved life of the fan's bearings.
- Without a commutator to wear out, the life of a DC brushless motor can be significantly longer compared to a DC motor using brushes and a commutator. Commutation also tends to cause a great deal of electrical and RF noise; without a commutator or brushes, a brushless motor may be used in electrically sensitive devices like audio equipment or computers.
- The same Hall Effect sensors that provide the commutation can also provide a convenient tachometer signal for closed-loop control (servo-controlled) applications. In fans, the tachometer signal can be used to derive a "fan OK" signal.
- The motor can be easily synchronized to an internal or external clock, leading to precise speed control.
- Brushless motors have no chance of sparking, unlike brushed motors, making them better suited to environments with volatile chemicals and fuels.
- Brushless motors are usually used in small equipment such as computers, and are generally used to get rid of unwanted heat.
- They are also very quiet motors, which is an advantage if being used in equipment that is affected by vibrations.

Modern DC brushless motors range in power from a fraction of a watt to many kilowatts. Larger brushless motors up to about 100 kW rating are used in electric vehicles. They also find significant use in high-performance electric model aircraft.

Coreless DC Motors

Nothing in the design of any of the motors described above requires that the iron (steel) portions of the rotor actually rotate; torque is exerted only on the windings of the electromagnets. Taking advantage of this fact is the coreless DC motor, a specialized form of a brush or brushless DC motor. Optimized for rapid acceleration, these motors have a rotor that is constructed without any iron core. The rotor can take the form of a winding-filled cylinder inside the stator magnets, a basket surrounding the stator magnets, or a flat pancake (possibly formed on a printed wiring board) running between upper and lower stator magnets. The windings are typically stabilized by being impregnated with electrical epoxy potting systems. Filled epoxies that have moderate mixed viscosity and a long gel time. These systems are highlighted by low shrinkage and low exotherm.

Because the rotor is much lighter in weight (mass) than a conventional rotor formed from copper windings on steel laminations, the rotor can accelerate much more rapidly, often achieving a mechanical time constant under 1 ms. This is especially true if the windings use aluminum rather than the heavier copper. But because there is no metal mass in the rotor to act as a heat sink, even small coreless motors must often be cooled by forced air. These motors were commonly used to drive the capstan(s) of magnetic tape drives and are still widely used in high-performance servo-controlled systems, like radio-controlled vehicles/aircraft, humanoid robotic systems, industrial automation, medical devices, etc.



STARTER MOTOR

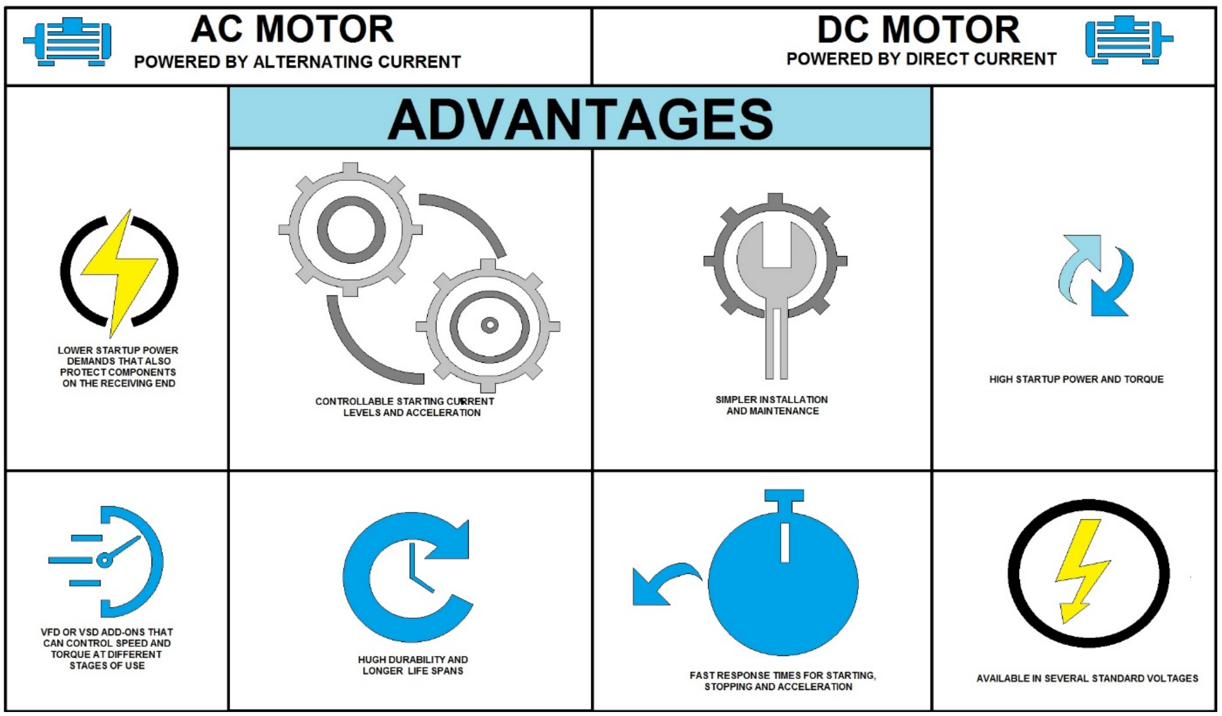
Universal Motors

A variant of the wound field DC motor is the universal motor. The name derives from the fact that it may use AC or DC supply current, although in practice they are nearly always used with AC supplies. The principle is that in a wound field DC motor the current in both the field and the armature (and hence the resultant magnetic fields) will alternate (reverse polarity) at the same time, and hence the mechanical force generated is always in the same direction. In practice, the motor must be specially designed to cope with the AC current (impedance must be taken into account, as must the pulsating force), and the resultant motor is generally less efficient than an equivalent pure DC motor.

Operating at normal power line frequencies, the maximum output of universal motors is limited and motors exceeding one kilowatt are rare. But universal motors also form the basis of the traditional railway traction motor in electric railways. In this application, to keep their electrical efficiency high, they were operated from very low frequency AC supplies, with 25 Hz and 16 2/3 hertz operation being common. Because they are universal motors, locomotives using this design were also commonly capable of operating from a third rail powered by DC.

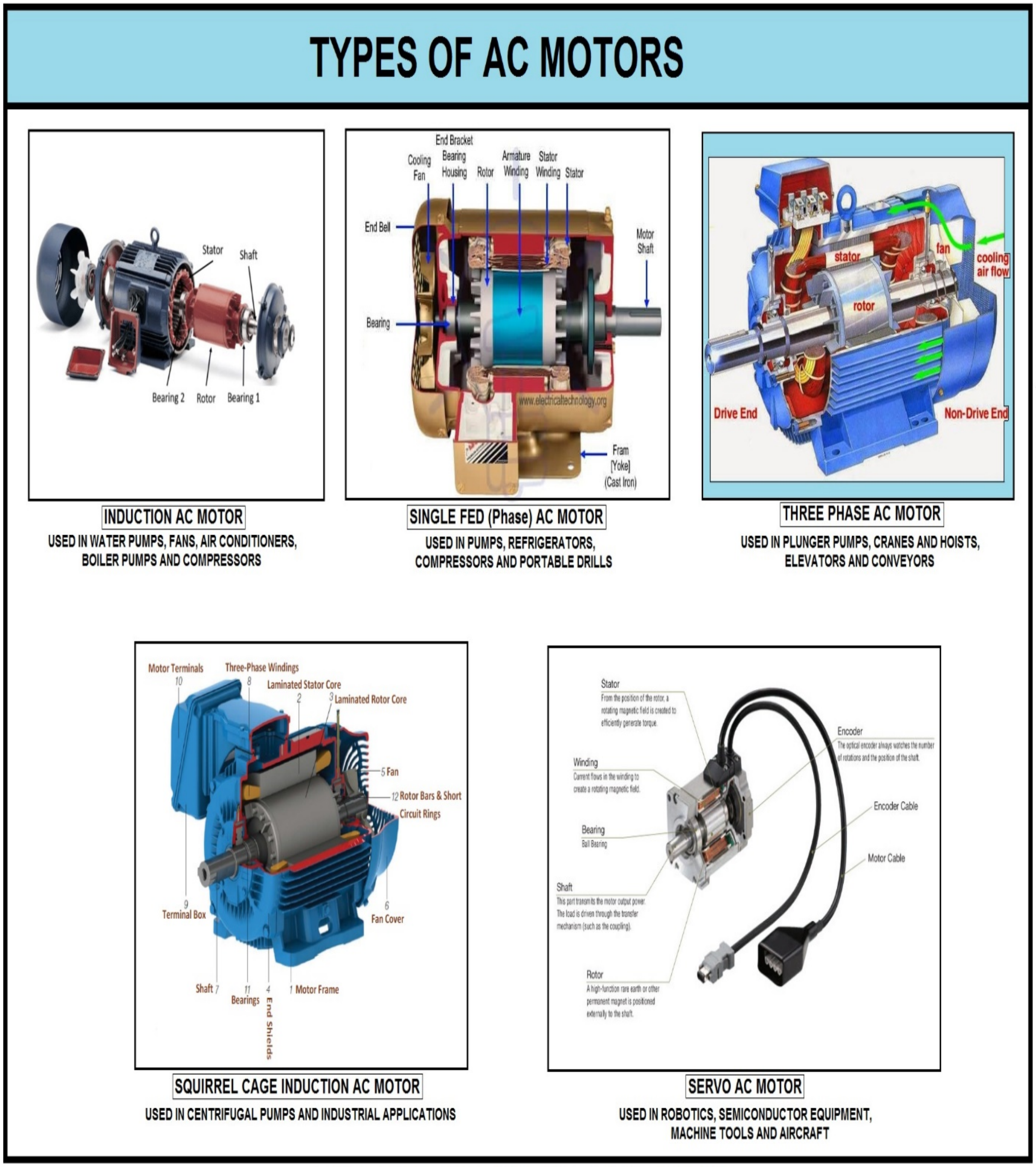
The advantage of the universal motor is that AC supplies may be used on motors which have the typical characteristics of DC motors, specifically high starting torque and very compact design if high running speeds are used. The negative aspect is the maintenance and short life problems caused by the commutator. As a result, such motors are usually used in AC devices such as food mixers and power tools which are used only intermittently.

Continuous speed control of a universal motor running on AC is very easily accomplished using a thyristor circuit, while stepped speed control can be accomplished using multiple taps on the field coil. Household blenders that advertise many speeds frequently combine a field coil with several taps and a diode that can be inserted in series with the motor (causing the motor to run on half-wave rectified AC).



AC / DC MOTOR COMPARISON

AC Motor Breakdown



TYPES OF AC MOTORS AND USES

In 1882, Nicola Tesla identified the rotating magnetic field principle, and pioneered the use of a rotary field of force to operate machines. He exploited the principle to design a unique two-phase induction motor in 1883. In 1885, Galileo Ferraris independently researched the concept. In 1888, Ferraris published his research in a paper to the Royal Academy of Sciences in Turin.

Introduction of Tesla's motor from 1888 onwards initiated what is sometimes referred to as the Second Industrial Revolution, making possible the efficient generation and long distance distribution of electrical energy using the alternating current transmission system, also of Tesla's invention (1888). Before the invention of the rotating magnetic field, motors operated by continually passing a conductor through a stationary magnetic field (as in homopolar motors). Tesla had suggested that the commutators from a machine could be removed and the device could operate on a rotary field of force. Professor Poeschel, his teacher, stated that would be akin to building a perpetual motion machine.

Components

A typical AC motor consists of two parts:

1. An outside stationary stator having coils supplied with AC current to produce a rotating magnetic field, and;
2. An inside rotor attached to the output shaft that is given a torque by the rotating field.

Torque motors

A torque motor is a specialized form of induction motor which is capable of operating indefinitely at stall (with the rotor blocked from turning) without damage. In this mode, the motor will apply a steady stall torque to the load (hence the name). A common application of a torque motor would be the supply- and take-up reel motors in a tape drive. In this application, driven from a low voltage, the characteristics of these motors allow a relatively-constant light tension to be applied to the tape whether or not the capstan is feeding tape past the tape heads.

Driven from a higher voltage, (and so delivering a higher torque), the torque motors can also achieve fast-forward and rewind operation without requiring any additional mechanics such as gears or clutches. In the computer world, torque motors are used with force feedback steering wheels.

Slip Ring

The slip ring or wound rotor motor is an induction machine where the rotor comprises a set of coils that are terminated in slip rings to which external impedances can be connected. The stator is the same as is used with a standard squirrel cage motor. By changing the impedance connected to the rotor circuit, the speed/current and speed/torque curves can be altered.

The slip ring motor is used primarily to start a high inertia load or a load that requires a very high starting torque across the full speed range. By correctly selecting the resistors used in the secondary resistance or slip ring starter, the motor is able to produce maximum torque at a relatively low current from zero speed to full speed. A secondary use of the slip ring motor is to provide a means of speed control.

Because the torque curve of the motor is effectively modified by the resistance connected to the rotor circuit, the speed of the motor can be altered. Increasing the value of resistance on the rotor circuit will move the speed of maximum torque down.

If the resistance connected to the rotor is increased beyond the point where the maximum torque occurs at zero speed, the torque will be further reduced. When used with a load that has a torque curve that increases with speed, the motor will operate at the speed where the torque developed by the motor is equal to the load torque.

Reducing the load will cause the motor to speed up, and increasing the load will cause the motor to slow down until the load and motor torque are equal. Operated in this manner, the slip losses are dissipated in the secondary resistors and can be very significant. The speed regulation is also very poor.

Stepper Motors

Closely related in design to three-phase AC synchronous motors are stepper motors, where an internal rotor containing permanent magnets or a large iron core with salient poles is controlled by a set of external magnets that are switched electronically.

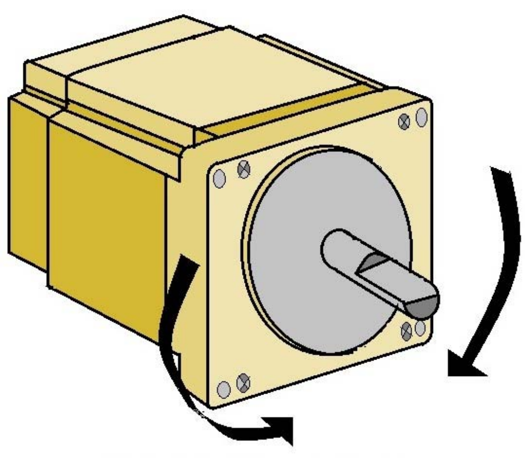
A stepper motor may also be thought of as a cross between a DC electric motor and a solenoid. As each coil is energized in turn, the rotor aligns itself with the magnetic field produced by the energized field winding.

Unlike a synchronous motor, in its application, the motor may not rotate continuously; instead, it "steps" from one position to the next as field windings are energized and de-energized in sequence. Depending on the sequence, the rotor may turn forwards or backwards.

Simple stepper motor drivers entirely energize or entirely de-energize the field windings, leading the rotor to "cog" to a limited number of positions; more sophisticated drivers can proportionally control the power to the field windings, allowing the rotors to position between the cog points and thereby rotate extremely smoothly. Computer controlled stepper motors are one of the most versatile forms of positioning systems, particularly when part of a digital servo-controlled system.

Stepper motors can be rotated to a specific angle with ease, and hence stepper motors are used in pre-gigabyte era computer disk drives, where the precision they offered was adequate for the correct positioning of the read/write head of a hard disk drive.

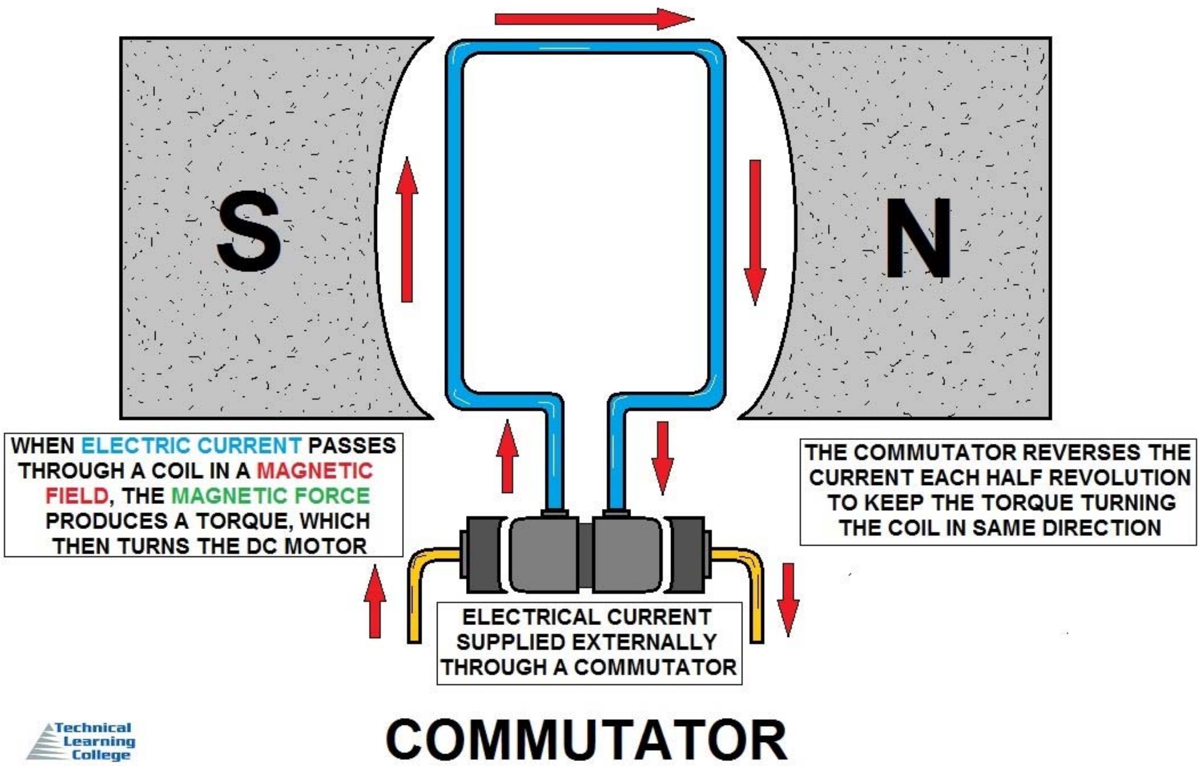
As drive density increased, the precision limitations of stepper motors made them obsolete for hard drives, thus newer hard disk drives use read/write head control systems based on voice coils. Stepper motors were upscaled to be used in electric vehicles under the term SRM (switched reluctance machine).



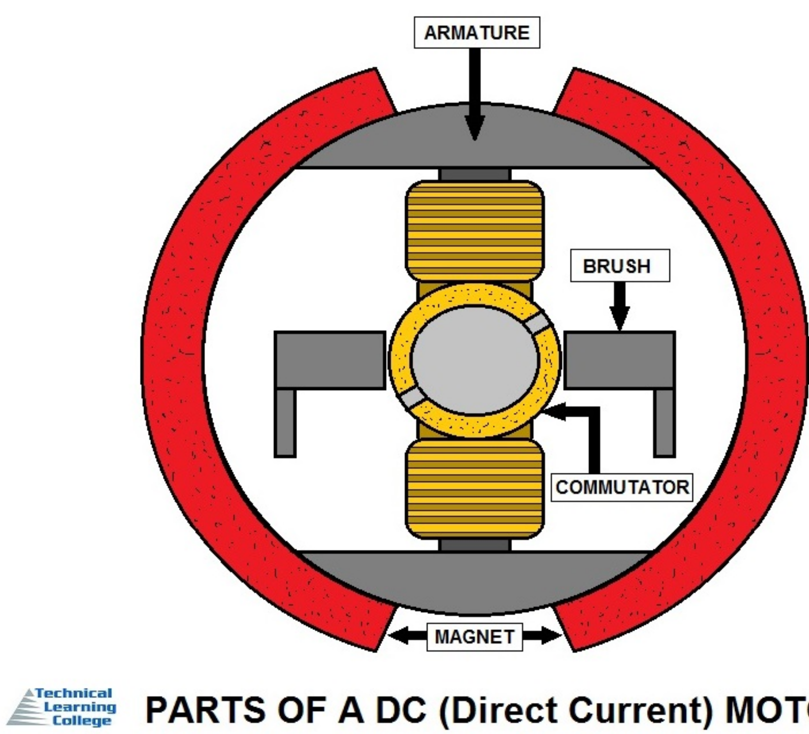
STEPPER MOTOR

Brushless, Synchronous Electric Motor that coverts digital pulses into shaft rotations

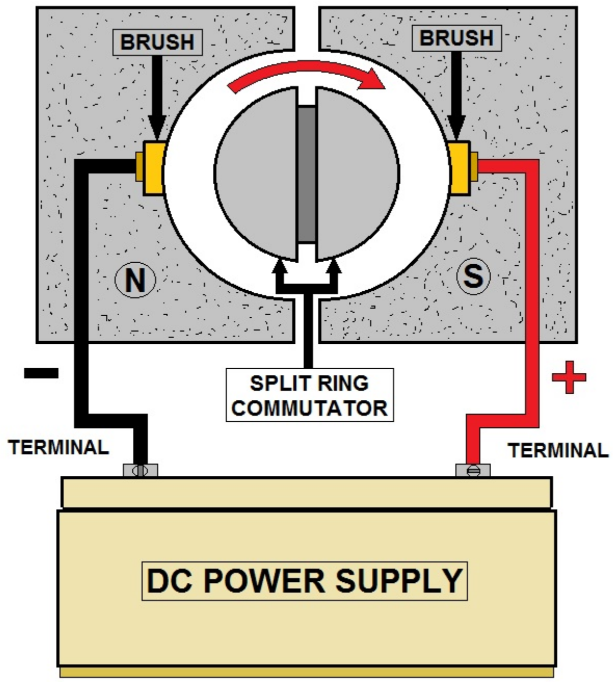
Motor Diagrams



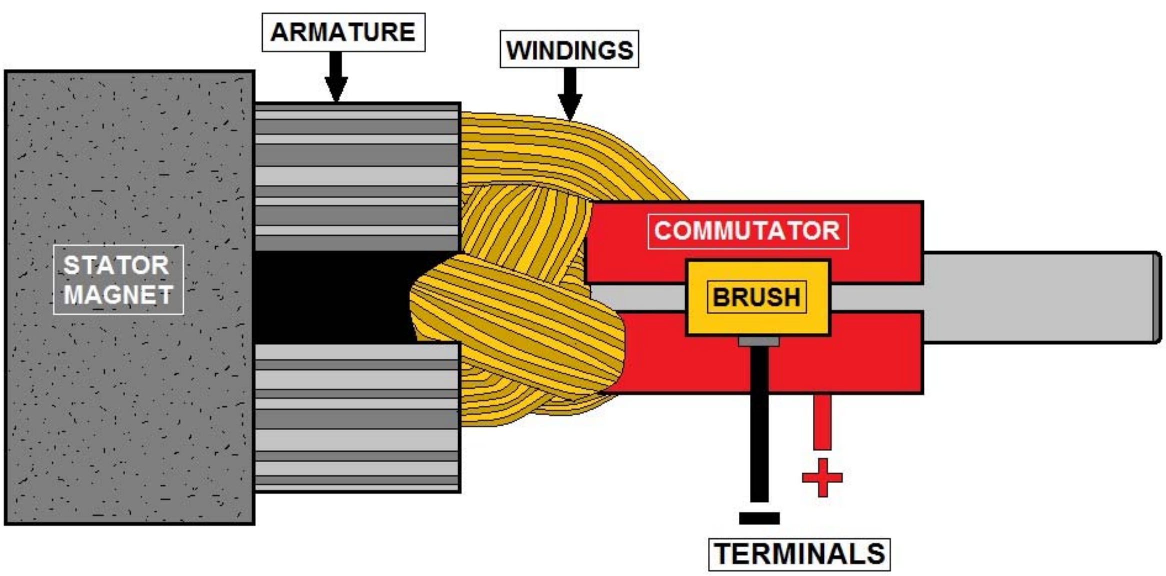
COMMUTATOR



PARTS OF A DC (Direct Current) MOTOR

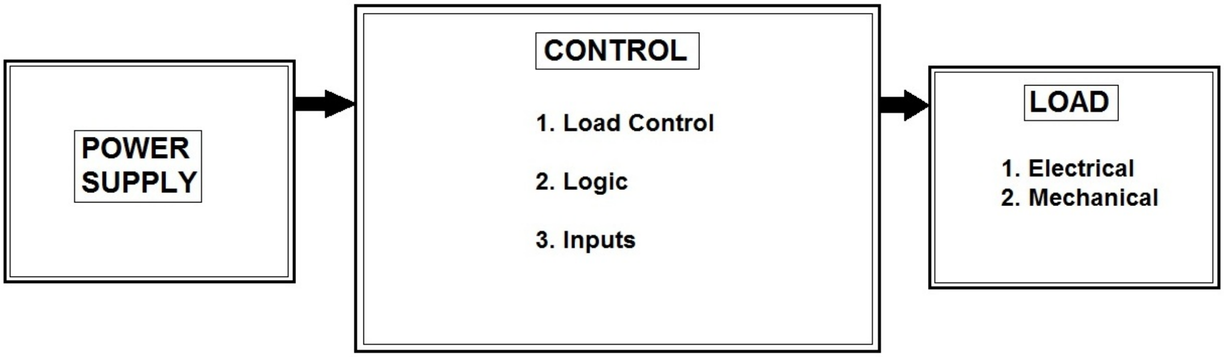


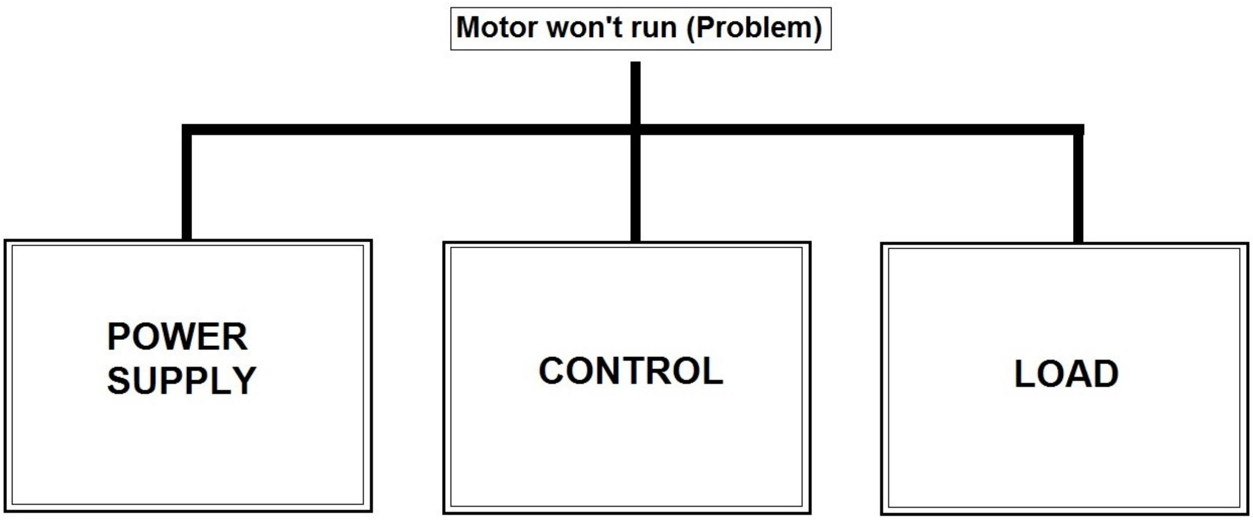
DC MOTOR

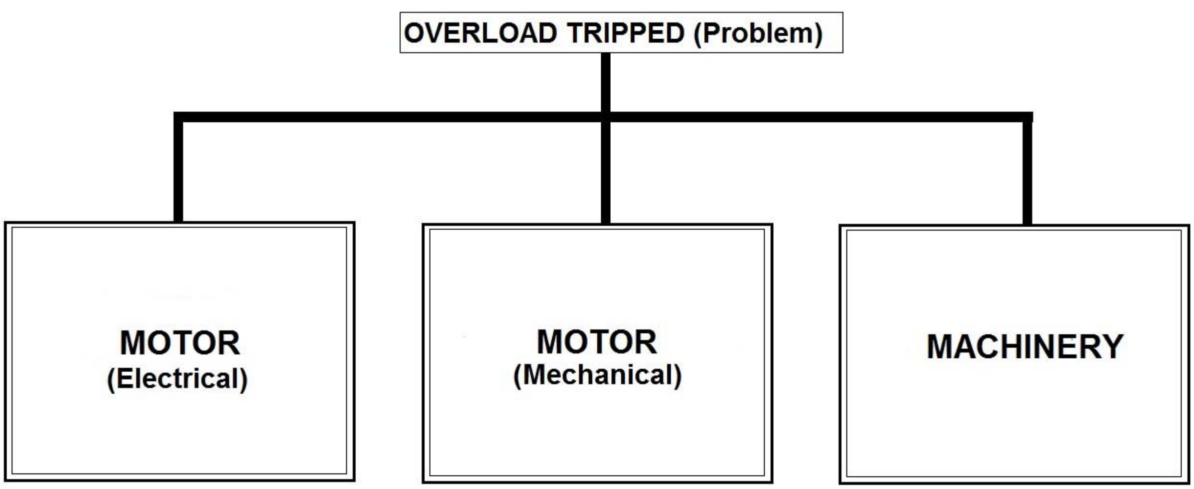


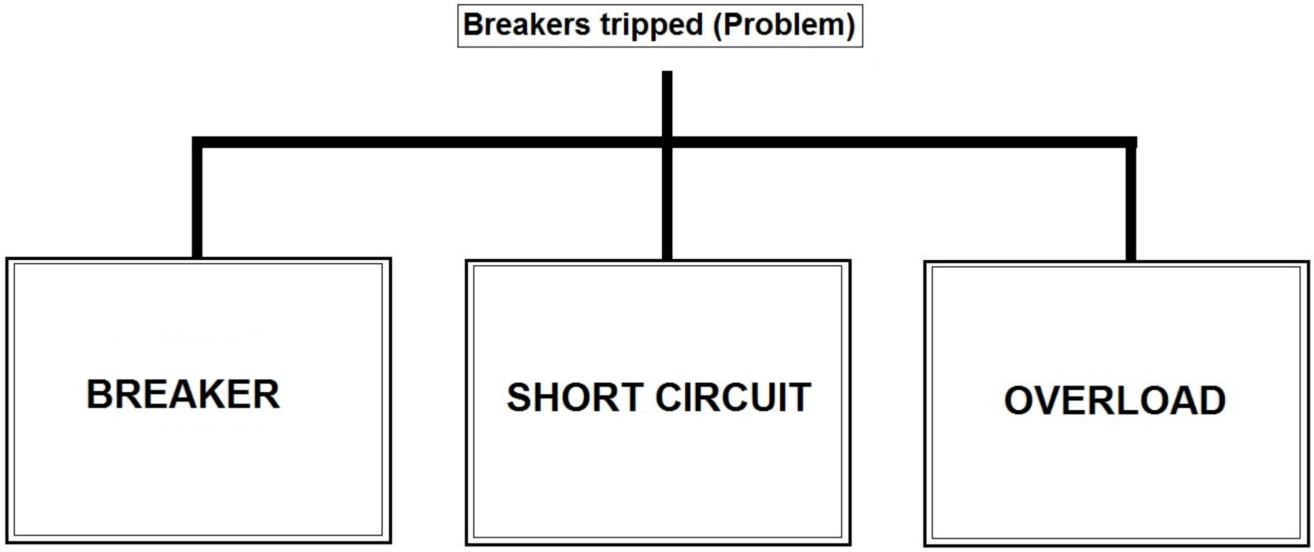
BRUSHED DC MOTOR

Motor Problem - Diagnosis Chart





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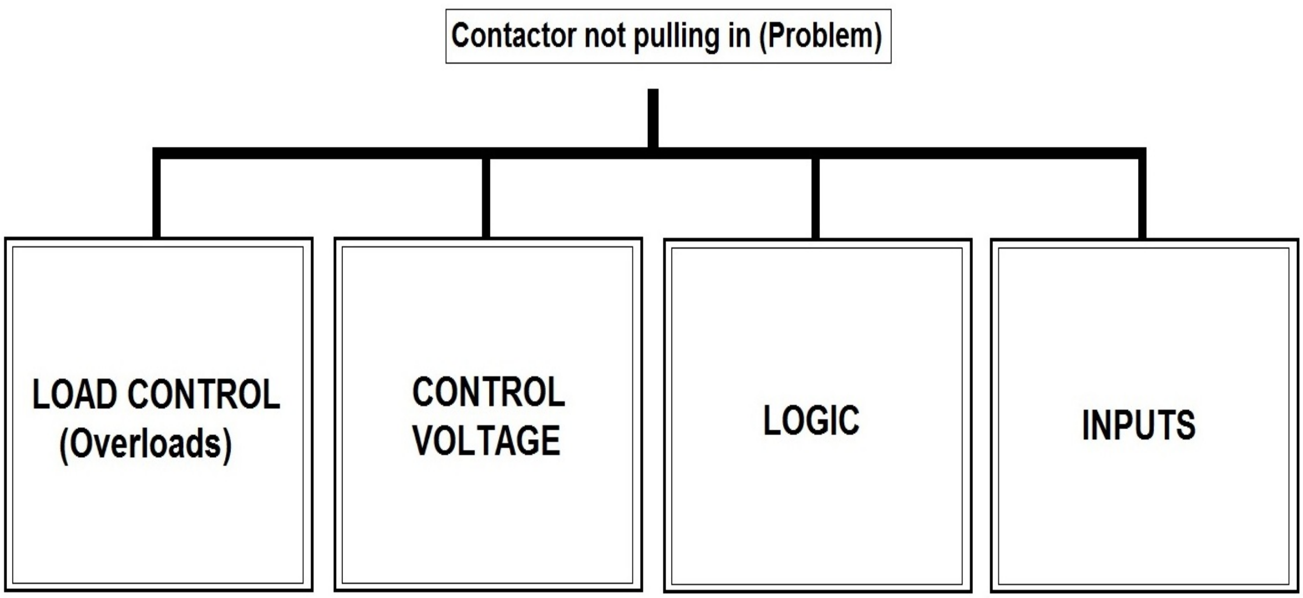
BREAKER
SHORT CIRCUIT
OVERLOAD


Contactor not pulling in (Problem)
LOAD CONTROL (Overloads)
CONTROL VOLTAGE
LOGIC
INPUTS

Motor Review Sub-Section

Reviewing D-C Motors
DC motors have been available for nearly 100 years. In fact the first electric motors were designed and built for operation from direct current power. AC motors are the basic prime movers for the fixed speed requirements of industry. Their basic simplicity, dependability and ruggedness make AC motors the natural choice for the vast majority of industrial drive applications.

An electric motor can be configured as a solenoid, a stepper motor or a rotational machine. This article covers the DC rotational machine. In all DC rotational machines, there are six components that comprise the electric motor: axle, rotor or armature, stator, commutator, field magnets and brushes.

In order to understand how a direct current (DC) electric motor operates, a few basic principles must be understood. Just as in Faraday's experiment, the DC motor works with magnetic fields and electrical current. Centuries ago it was discovered that a stone found in Asia, referred to as a lodestone, and had an unusual property that would transfer an invisible force to an iron object when the stone was rubbed against it. These lodestones were found to align with the earth's north-south axis when freely hanging on a string or floated on water, and this property aided early explorers in navigating around the earth.

It was understood later that this stone was a permanent magnet with a field that had two poles of opposite effect, referred to as north and south. The magnetic fields, just like electric charges, have forces that are opposite in their effects. Electric charges are either positive or negative, whereas magnetic fields have a north-south orientation. When magnetic fields are aligned at opposite or dissimilar poles, they'll exert considerable forces of attraction with one another, and when aligned at like or similar poles, they'll strongly repel one another.

The magnetic field will pull or put a force upon a ferrous (magnetic) material. If iron particles are sprinkled on a paper sheet over a permanent magnet, the alignment of the iron particles maps the magnetic field, which shows that this field leaves one pole and enters the other pole with the force field being unbroken. As with any kind of field (electric, magnetic or gravitational), the total quantity, or effect, of the field is referred to as the flux, while the push causing the flux to form in space is called a force. This magnetic force field is comprised of many lines of flux, all starting at one pole and returning to the other pole.

Modern Theory of Magnetism
The modern theory of magnetism states that a magnetic field is produced by an electric charge in motion. When an electric charge is in motion, the electrons orbiting the atom are forced to align and uniformly spin in the same direction. The more atoms uniformly spinning in the same direction, the stronger the force of the magnetic field. When billions of atoms have orbits spinning in the same direction and the material is capable of holding the atoms' orbits, a permanent magnet is created.

When two powerful permanent magnets are moved in close proximity to one another, it's evident that a very real force is exerted that can provide the potential for work to be done. For work to be accomplished, the relationship between the magnetic fields must be controlled properly.

The trick here is to control the magnetic fields by a means other than just using the permanent magnet. This can be accomplished by producing a magnetic field with an electrical conductor that has current flowing through it.

Nearly all electric motors exploit the use of a current-carrying conductor to create mechanical work. When current is flowing through a conductor and the electric charge is in motion, the electrons orbiting the atoms are forced to align and uniformly spin in the same direction. This creates a magnetic field that forms around the conductor. The larger the current flowing through the conductor, the more atoms are forced to align and rotate in a uniform direction.

This rotational alignment of the atoms increases the strength of the magnetic field. However, if one were to place a conductor with current flowing through it near a permanent magnet, he would be disappointed by how feeble this force is. What's needed is a way to amplify the magnetic force field. This is accomplished by taking the conductor wire and making many turns or wraps to produce a winding. Converting the conductor from a single, isolated straight wire to one that contains many turns forming a winding amplifies the magnetic force many times. The amount of magnetic field amplification is based on the number of turns in the winding and the amount of current flowing through the conductor.

In this configuration, the magnetic flux is moving through air, which is a poor conductor of magnetic energy, thus allowing the magnetic flux to spread out over a very wide area. Therefore, the reluctance from the magnetic field when moving through air is quite high. Reluctance is a measure of how difficult it is for the magnetic flux to complete its circuit—that is, to leave one pole and enter the opposite pole. If the magnetic flux is kept close to the magnet, it has less resistance or opposition to flow.

Magnetic Principles and Motor Theory

All machine designs involving rotating equipment ultimately rely on theory to guide the engineer's application choices. Hence, a very brief review of magnetic principles and motor theory is always a convenient starting point for any discussion of DC motor applications. The laws of physics have blessed the world of machine design with the existence of magnetism, which is the foundation of motor theory. In essence, magnets, permanent or electromagnetic, produce fields of magnetic flux. These magnetic fields can produce an induced EMF through a coil of wire when relative movement between the field and a current carrying conductor occurs; and if this movement is reversed, so is the direction of the magnetic field, according to Faraday's Law. Thus, in theory, motor action or torque is produced when electrical energy is applied to conductor in a changing magnetic field, causing current flow in the conductor, generating both an induced EMF and a CEMF (Lenz's Law) resulting in rotational or mechanical energy.

DC Motors: Physical and Functional Descriptions

DC motors are commonly used in industrial machinery because of their inherent advantages—good speed control, high starting torque, reliable control methodology—which generally outweigh the increased maintenance costs associated with them.

Construction

The generic DC motor is constructed 13 with armature and field windings, interpoles, a frame or stator, a segmented commutator, a brush assembly and end bells. The rotating armature winding is wound on a laminated core, mounted on a steel shaft, supported by shaft bearings, and is connected to the segmented commutator that receives external DC power through the brush assembly. Brushes conduct the current from external DC power circuit to the commutator and finally to the armature windings. The frame or stator supports the field windings and interpoles. The end bells encase all the parts of the motor into one unit.

Operation
DC motors produce torque and mechanical motion due to the interaction of the magnetic fields of the rotating armature coil and the stationary field coil mounted on the frame. The changing magnetic field of the armature is possible through the use of electrically conductive carbon brushes, which ride on the segmented, commutator ring; external DC power is applied to the brushes through the commutator to the armature windings. As current flows through the armature coil, a magnetic field results. The field windings mounted on the frame, also set up a magnetic field. After the rotating armature passes through half of a complete rotation, the commutator switches the direction of the current flow, thereby changing the direction of the magnetic field in the armature winding. This change produces opposing magnetic fields and sustains torque and rotation through the next half cycle of rotation until the commutator changes the direction of current flow and the magnetic field again.

Types
The field and armature windings of DC motors can be connected in series, shunt (parallel) or series-shunt to achieve different kinds of speed-torque characteristics. Hence, the three general categories of wound field DC motors are shunt-wound, series-wound and compound-wound. In series-wound motors, the armature is connected in series with the field to provide high starting torque; however, they do not operate at no-load: when speed decreases, torque increases, which can create a possibly unsafe runaway condition. In shunt wound motors, the armature and field are connected in parallel. This wiring arrangement produces an inverse speed-torque relationship: as speed increases, torque decreases. The compound-wound is a combination of a series- and shunt-wound motor by placing the field winding in series with the armature in addition to a shunt field. This type offers a combination of good starting torque and speed control.

Brushless motors are a hybrid type of DC motor that does not use a commutator. Rather, it is constructed with a permanent magnet rotor, optical shaft encoder that gives positional feedback information, a DC controller that excites the phase of stator windings required to develop torque based upon the encoder’s feedback. Brushless motors characteristically have high maximum operating speeds, high torque to weight ratios and are compact in design (fractional horsepower). They are typically used in robotic arm applications.

Associated Solid State Controls
In order to supply the answer, it is necessary to examine some of the basic characteristics obtainable from DC motors and their associated solid state controls.

1. Wide speed range.
2. Good speed regulation.
3. Compact size and light weight (relative to mechanical variable speed).
4. Ease of control.
5. Low maintenance.
6. Low cost.

In order to realize how a DC drive has the capability to provide the above characteristics, the DC drive has to be analyzed as two elements that make up the package. These two elements are of course the motor and the control. (The "control" is more accurately called the "regulator"). Basic DC motors as used on nearly all packaged drives have a very simple performance characteristic the shaft turns at a speed almost directly proportional to the voltage applied to the armature.

External Adjustment
In addition to the normal external adjustment such as the speed potentiometer. there are a number of common internal adjustments that are used on simple small analog type SCR Drives (Silicon Controlled Rectifier Drive). Some of these adjustments are as follows:

- ✓ Minimum Speed
- ✓ Maximum Speed
- ✓ Current Limit (Torque Limit) . IR Compensation
- ✓ Acceleration Time . Deceleration Time

The following is a description of the function that these individual adjustments serve and their typical use.

Minimum Speed
In most cases when the control is initially installed the speed potentiometer can be turned down to its lowest point and the output voltage from the control will go to zero causing the motor to stop. There are many situations where this is not desirable. For example there are some machines that want to be kept running at a minimum speed and accelerated up to operating speed as necessary. There is also a possibility that an operator may use the speed potentiometer to stop the motor to work on the machine. This can be a dangerous situation since the motor has only been brought to a stop by zeroing the input signal voltage. A more desirable situation is when the motor is stopped by opening the circuit to the motor or power to the control using the on/off switch. By adjusting the minimum speed up to some point where the motor continues to run even with the speed potentiometer set to its lowest point, the operator must shut the control off to stop the motor. This adds a little safety into the system. The typical minimum speed adjustment is from 0 to 30% of motor base speed.

Maximum Speed
The maximum speed adjustment sets the maximum speed attainable either by raising the input signal to its maximum point or turning the potentiometer to the maximum point. For example on a typical DC motor the rated speed of the motor might 1750 RPM but the control might be capable of running it up to 1850 or 1900 RPM. In some cases it's desirable to limit the motor (and machine speed) to something less than would be available at this maximum setting. The maximum adjustment allows this to be done. By turning the internal potentiometer to a lower point the maximum output voltage from the control is limited. This limits the maximum speed available from the motor. In typical controls such as our BC140 the range of adjustment on the maximum speed is from 50 to 110% of motor base speed.

Current Limit
One very nice feature of electronic speed controls is that the current going to the motor is constantly monitored by the control. As mentioned previously, the current drawn by the armature of the DC motor is related to the torque that is required by the load. Since this monitoring and control is available an adjustment is provided in the control that limits the output current to a maximum value.

This function can be used to set a threshold point that will cause the motor to stall rather than putting out an excessive amount of torque. This capability gives the motor/control combination the ability to prevent damage that might otherwise occur if higher values of torque were available. This is handy on machines that might become jammed or otherwise stalled. It can also be used where the control is operating a device such as the center winder where the important thing becomes torque rather than the speed. In this case the current limit is set and the speed goes up or down to hold the tension 0 the material being wound.

The current limit is normally factory set at 150% of the motor's rated current. This allows the motor to produce enough torque to start and accelerate the load and yet will not let the current (and torque) exceed 150% of its rated value when running. The range of adjustment is typically from 0 to 200% of the motor rated current.

IR Compensation
IR compensation is a method used to adjust for the droop in a motor's speed due to armature resistance. As mentioned previously, IR compensation is positive feedback that causes the control output voltage to rise slightly with increasing output current. This will help stabilize the motor's speed from a no load to full load condition. If the motor happens to be driving a load where the torque is constant or nearly so, then this adjustment is usually unnecessary. However, if the motor is driving a load with a widely fluctuating torque requirement, and speed regulation is critical, then IR compensation can be adjusted to stabilize the speed from the light load to full load condition.

One caution is that when IR compensation is adjusted too high it results in an increasing speed characteristic. This means that as the load is applied the motor is actually going to be forced to run faster. When this happens it increases the voltage and current to the motor which in turn increases the motor speed further. If this adjustment is set too high an unstable "hunting" or oscillating condition occurs that is undesirable.

Acceleration Time Adjustment
The Acceleration Time adjustment performs the function that is indicated by its name. It will extend or shorten the amount of time for the motor to go from zero speed up to the set speed. It also regulates the time it takes to change speeds from one setting (say 50%) to another setting (perhaps 100%). So this setting has the ability to moderate the acceleration rate on the drive.

A couple notes are important: if an acceleration time that is too rapid is called for "acceleration time" will be overridden by the current limit. Acceleration will only occur at a rate that is allowed by the amount of current the control passes through to the motor. Also important to note is that on most small controls the acceleration time is not linear. What this means is that a change of 50 RPM may occur more rapidly when the motor is at low speed than it does when the motor is approaching the set point speed. This is important to know but usually not critical on simple applications where these drives are used.

Deceleration Time
This is an adjustment that allows loads to be slowed over an extended period of time. For example, if power is removed from the motor and the load stops in 3 seconds, then the decel time adjustment would allow you ”to increase that time and "power down" the load over a period of 4, 5, 6 or more seconds. Note: On a conventional simple DC drive it will not allow for the shortening of the time below the "coast to rest" time.

Adjustment Summary
The ability to adjust these six adjustments gives great flexibility to the typical inexpensive DC drive. In most cases the factory preset settings are adequate and need not be changed, but on other applications it may be desirable to tailor the characteristics of the control to the specific application. Many of these adjustments are available in other types of controls, such as variable frequency drives.

Reviewing A-C Motors

AC Motor History

In 1882, Nikola Tesla discovered the rotating magnetic field, and pioneered the use of a rotary field of force to operate machines. He exploited the principle to design a unique two-phase induction motor in 1883. In 1885, Galileo Ferraris independently researched the concept. In 1888, Ferraris published his research in a paper to the Royal Academy of Sciences in Turin. Tesla had suggested that the commutators from a machine could be removed and the device could operate on a rotary field of force. Professor Poeschel, his teacher, stated that would be akin to building a perpetual motion machine.

Michail Osipovich Dolivo-Dobrovolsky later developed a three-phase "cage-rotor" in 1890. This type of motor is now used for the vast majority of commercial applications.

An AC motor has two parts: a stationary stator having coils supplied with alternating current to produce a rotating magnetic field, and a rotor attached to the output shaft that is given a torque by the rotating field.

AC Motor with Sliding Rotor

A conical-rotor brake motor incorporates the brake as an integral part of the conical sliding rotor. When the motor is at rest, a spring acts on the sliding rotor and forces the brake ring against the brake cap in the motor, holding the rotor stationary. When the motor is energized, its magnetic field generates both an axial and a radial component. The axial component overcomes the spring force, releasing the brake; while the radial component causes the rotor to turn. There is no additional brake control required.

Synchronous Electric Motor

A synchronous electric motor is an AC motor distinguished by a rotor spinning with coils passing magnets at the same rate as the alternating current and resulting magnetic field which drives it. Another way of saying this is that it has zero slip under usual operating conditions. Contrast this with an induction motor, which must slip to produce torque. One type of synchronous motor is like an induction motor except the rotor is excited by a DC field. Slip rings and brushes are used to conduct current to the rotor. The rotor poles connect to each other and move at the same speed hence the name synchronous motor.

Another type, for low load torque, has flats ground onto a conventional squirrel-cage rotor to create discrete poles. Yet another, such as made by Hammond for its pre-World War II clocks, and in the older Hammond organs, has no rotor windings and discrete poles. It is not self-starting. The clock requires manual starting by a small knob on the back, while the older Hammond organs had an auxiliary starting motor connected by a spring-loaded manually operated switch.

Finally, hysteresis synchronous motors typically are (essentially) two-phase motors with a phase-shifting capacitor for one phase. They start like induction motors, but when slip rate decreases sufficiently, the rotor (a smooth cylinder) becomes temporarily magnetized. Its distributed poles make it act like a permanent-magnet-rotor synchronous motor. The rotor material, like that of a common nail, will stay magnetized, but can also be demagnetized with little difficulty. Once running, the rotor poles stay in place; they do not drift.

Low-power synchronous timing motors (such as those for traditional electric clocks) may have multi-pole permanent-magnet external cup rotors, and use shading coils to provide starting torque. Telechron clock motors have shaded poles for starting torque, and a two-spoke ring rotor that performs like a discrete two-pole rotor.

Induction Motor

An induction motor is an asynchronous AC motor where power is transferred to the rotor by electromagnetic induction, much like transformer action. An induction motor resembles a rotating transformer, because the stator (stationary part) is essentially the primary side of the transformer and the rotor (rotating part) is the secondary side. PolypAhase induction motors are widely used in industry.

Induction motors may be further divided into squirrel-cage motors and wound-rotor motors. Squirrel-cage motors have a heavy winding made up of solid bars, usually aluminum or copper, joined by rings at the ends of the rotor. When one considers only the bars and rings as a whole, they are much like an animal's rotating exercise cage, hence the name.

Currents induced into this winding provide the rotor magnetic field. The shape of the rotor bars determines the speed-torque characteristics. At low speeds, the current induced in the squirrel cage is nearly at line frequency and tends to be in the outer parts of the rotor cage. As the motor accelerates, the slip frequency becomes lower, and more current is in the interior of the winding. By shaping the bars to change the resistance of the winding portions in the interior and outer parts of the cage, effectively a variable resistance is inserted in the rotor circuit. However, the majority of such motors have uniform bars.

In a wound-rotor motor, the rotor winding is made of many turns of insulated wire and is connected to slip rings on the motor shaft. An external resistor or other control devices can be connected in the rotor circuit. Resistors allow control of the motor speed, although significant power is dissipated in the external resistance. A converter can be fed from the rotor circuit and return the slip-frequency power that would otherwise be wasted back into the power system through an inverter or separate motor-generator.

The wound-rotor induction motor is used primarily to start a high inertia load or a load that requires a very high starting torque across the full speed range. By correctly selecting the resistors used in the secondary resistance or slip ring starter, the motor is able to produce maximum torque at a relatively low supply current from zero speed to full speed. This type of motor also offers controllable speed.

Motor speed can be changed because the torque curve of the motor is effectively modified by the amount of resistance connected to the rotor circuit. Increasing the value of resistance will move the speed of maximum torque down. If the resistance connected to the rotor is increased beyond the point where the maximum torque occurs at zero speed, the torque will be further reduced.

When used with a load that has a torque curve that increases with speed, the motor will operate at the speed where the torque developed by the motor is equal to the load torque. Reducing the load will cause the motor to speed up, and increasing the load will cause the motor to slow down until the load and motor torque are equal. Operated in this manner, the slip losses are dissipated in the secondary resistors and can be very significant. The speed regulation and net efficiency is also very poor.

Various regulatory authorities in many countries have introduced and implemented legislation to encourage the manufacture and use of higher efficiency electric motors.

Doubly Fed Electric Motor
Doubly fed electric motors have two independent multiphase winding sets, which contribute active (i.e., working) power to the energy conversion process, with at least one of the winding sets electronically controlled for variable speed operation. Two independent multiphase winding sets (i.e., dual armature) are the maximum provided in a single package without topology duplication. Doubly fed electric motors are machines with an effective constant torque speed range that is twice synchronous speed for a given frequency of excitation. This is twice the constant torque speed range as singly fed electric machines, which have only one active winding set.

A doubly fed motor allows for a smaller electronic converter but the cost of the rotor winding and slip rings may offset the saving in the power electronics components. Difficulties with controlling speed near synchronous speed limit applications.

Singly Fed Electric Motor
Most AC motors are singly fed. Singly fed electric motors have a single multiphase winding set that is connected to a power supply. Singly fed electric machines may be either induction or synchronous. The active winding set can be electronically controlled. Singly fed electric machines have an effective constant torque speed range up to synchronous speed for a given excitation frequency.

Torque Motors
A torque motor (also known as a limited torque motor) is a specialized form of induction motor which is capable of operating indefinitely while stalled, that is, with the rotor blocked from turning, without incurring damage. In this mode of operation, the motor will apply a steady torque to the load (hence the name).

A common application of a torque motor would be the supply- and take-up reel motors in a tape drive. In this application, driven from a low voltage, the characteristics of these motors allow a relatively constant light tension to be applied to the tape whether or not the capstan is feeding tape past the tape heads. Driven from a higher voltage, (and so delivering a higher torque), the torque motors can also achieve fast-forward and rewind operation without requiring any additional mechanics such as gears or clutches. In the computer gaming world, torque motors are used in force feedback steering wheels.

Another common application is the control of the throttle of an internal combustion engine in conjunction with an electronic governor. In this usage, the motor works against a return spring to move the throttle in accordance with the output of the governor. The latter monitors engine speed by counting electrical pulses from the ignition system or from a magnetic pickup and, depending on the speed, makes small adjustments to the amount of current applied to the motor.

If the engine starts to slow down relative to the desired speed, the current will be increased, the motor will develop more torque, pulling against the return spring and opening the throttle. Should the engine run too fast, the governor will reduce the current being applied to the motor, causing the return spring to pull back and close the throttle.

Stepper Motors

Closely related in design to three-phase AC synchronous motors are stepper motors, where an internal rotor containing permanent magnets or a magnetically soft rotor with salient poles is controlled by a set of external magnets that are switched electronically. A stepper motor may also be thought of as a cross between a DC electric motor and a rotary solenoid. As each coil is energized in turn, the rotor aligns itself with the magnetic field produced by the energized field winding. Unlike a synchronous motor, in its application, the stepper motor may not rotate continuously; instead, it "steps"—starts and then quickly stops again—from one position to the next as field windings are energized and de-energized in sequence. Depending on the sequence, the rotor may turn forwards or backwards, and it may change direction, stop, speed up or slow down arbitrarily at any time.

Simple stepper motor drivers entirely energize or entirely de-energize the field windings, leading the rotor to "cog" to a limited number of positions; more sophisticated drivers can proportionally control the power to the field windings, allowing the rotors to position between the cog points and thereby rotate extremely smoothly. This mode of operation is often called microstepping. Computer controlled stepper motors are one of the most versatile forms of positioning systems, particularly when part of a digital servo-controlled system.

Stepper motors can be rotated to a specific angle in discrete steps with ease, and hence stepper motors are used for read/write head positioning in computer floppy diskette drives. They were used for the same purpose in pre-gigabyte era computer disk drives, where the precision and speed they offered was adequate for the correct positioning of the read/write head of a hard disk drive.

As drive density increased, the precision and speed limitations of stepper motors made them obsolete for hard drives—the precision limitation made them unusable, and the speed limitation made them uncompetitive—thus newer hard disk drives use voice coil-based head actuator systems. (The term "voice coil" in this connection is historic; it refers to the structure in a typical (cone type) loudspeaker. This structure was used for a while to position the heads. Modern drives have a pivoted coil mount; the coil swings back and forth, something like a blade of a rotating fan. Nevertheless, like a voice coil, modern actuator coil conductors (the magnet wire) move perpendicular to the magnetic lines of force.)

Stepper motors were and still are often used in computer printers, optical scanners, and digital photocopiers to move the optical scanning element, the print head carriage (of dot matrix and inkjet printers), and the platen or feed rollers. Likewise, many computer plotters (which since the early 1990s have been replaced with large-format inkjet and laser printers) used rotary stepper motors for pen and platen movement; the typical alternatives here were either linear stepper motors or servomotors with closed-loop analog control systems.

So-called quartz analog wristwatches contain the smallest commonplace stepping motors; they have one coil, draw very little power, and have a permanent-magnet rotor. The same kind of motor drives battery-powered quartz clocks. Some of these watches, such as chronographs, contain more than one stepping motor.

Rotary

Uses include rotating machines such as fans, turbines, drills, the wheels on electric cars, locomotives and conveyor belts. Also, in many vibrating or oscillating machines, an electric motor spins an unbalanced mass, causing the motor (and its mounting structure) to vibrate. A familiar application is cell phone vibrating alerts used when the acoustic "ringer" is disabled by the user.

Electric motors are also popular in robotics. They turn the wheels of vehicular robots, and servo motors operate arms in industrial robots; they also move arms and legs in humanoid robots. In flying robots, along with helicopters, a motor rotates a propeller, or aerodynamic rotor blades to create controllable amounts of lift. Electric motors are replacing hydraulic cylinders in airplanes and military equipment.

In industrial and manufacturing businesses, electric motors rotate saws and blades in cutting and slicing processes; they rotate parts being turned in lathes and other machine tools, and spin grinding wheels. Fast, precise servo motors position tools and work in modern CNC machine tools. Motor-driven mixers are very common in food manufacturing. Linear motors are often used to push products into containers horizontally.

Many kitchen appliances also use electric motors. Food processors and grinders spin blades to chop and break up foods. Blenders use electric motors to mix liquids, and microwave ovens use motors to turn the tray that food sits on. Toaster ovens also use electric motors to turn a conveyor to move food over heating elements.

Servo Motor
A servomotor is a motor, very often sold as a complete module, which is used within a position-control or speed-control feedback control system mainly control valves, such as motor operated control valves.

Servomotors are used in applications such as machine tools, pen plotters, and other process systems. Motors intended for use in a servomechanism must have well-documented characteristics for speed, torque, and power. The speed vs. torque curve is quite important and is high ratio for a servo motor.

Dynamic response characteristics such as winding inductance and rotor inertia are also important; these factors limit the overall performance of the servomechanism loop. Large, powerful, but slow-responding servo loops may use conventional AC or DC motors and drive systems with position or speed feedback on the motor. As dynamic response requirements increase, more specialized motor designs such as coreless motors are used.

A servo system differs from some stepper motor applications in that the position feedback is continuous while the motor is running; a stepper system relies on the motor not to "miss steps" for short term accuracy, although a stepper system may include a "home" switch or other element to provide long-term stability of control. For instance, when a typical dot matrix computer printer starts up, its controller makes the print head stepper motor drive to its left-hand limit, where a position sensor defines home position and stops stepping. As long as power is on, a bidirectional counter in the printer's microprocessor keeps track of print-head position.

Linear Motor

A linear motor is essentially any electric motor that has been "unrolled" so that, instead of producing a torque (rotation), it produces a straight-line force along its length. Linear motors are most commonly induction motors or stepper motors. Linear motors are commonly found in many roller-coasters where the rapid motion of the motorless railcar is controlled by the rail. They are also used in maglev trains, where the train "flies" over the ground. On a smaller scale, the HP 7225A pen plotter, released in 1978, used two linear stepper motors to move the pen along the X and Y axes.

Torque Capability of Motor Types
When optimally designed within a given core saturation constraint and for a given active current (i.e., torque current), voltage, pole-pair number, excitation frequency (i.e., synchronous speed), and air-gap flux density, all categories of electric motors or generators will exhibit virtually the same maximum continuous shaft torque (i.e., operating torque) within a given air-gap area with winding slots and back-iron depth, which determines the physical size of electromagnetic core.

Some applications require bursts of torque beyond the maximum operating torque, such as short bursts of torque to accelerate an electric vehicle from standstill. Always limited by magnetic core saturation or safe operating temperature rise and voltage, the capacity for torque bursts beyond the maximum operating torque differs significantly between categories of electric motors or generators.

Capacity for bursts of torque should not be confused with field weakening capability inherent in fully electromagnetic electric machines (Permanent Magnet (PM) electric machine are excluded). Field weakening, which is not available with PM electric machines, allows an electric machine to operate beyond the designed frequency of excitation.

Electric machines without a transformer circuit topology, such as Field-Wound (i.e., electromagnet) or Permanent Magnet (PM) Synchronous electric machines cannot realize bursts of torque higher than the maximum designed torque without saturating the magnetic core and rendering any increase in current as useless. Furthermore, the permanent magnet assembly of PM synchronous electric machines can be irreparably damaged, if bursts of torque exceeding the maximum operating torque rating are attempted.

Electric machines with a transformer circuit topology, such as Induction (i.e., asynchronous) electric machines, Induction Doubly Fed electric machines, and Induction or Synchronous Wound-Rotor Doubly Fed (WRDF) electric machines, exhibit very high bursts of torque because the active current (i.e., Magneto-Motive-Force or the product of current and winding-turns) induced on either side of the transformer oppose each other and as a result, the active current contributes nothing to the transformer coupled magnetic core flux density, which would otherwise lead to core saturation.

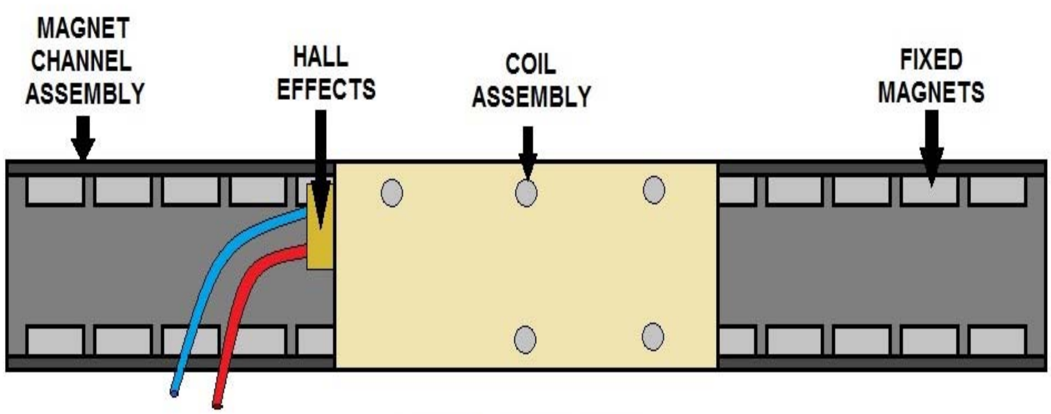
Electric machines that rely on Induction or Asynchronous principles short-circuit one port of the transformer circuit and as a result, the reactive impedance of the transformer circuit becomes dominant as slip increases, which limits the magnitude of active (i.e., real) current. Still, bursts of torque that are two to three times higher than the maximum design torque are realizable.

The Synchronous WRDF electric machine is the only electric machine with a truly dual ported transformer circuit topology (i.e., both ports independently excited with no short-circuited port). The dual ported transformer circuit topology is known to be unstable and requires a multiphase slip-ring-brush assembly to propagate limited power to the rotor winding set.

If a precision means were available to instantaneously control torque angle and slip for synchronous operation during motoring or generating while simultaneously providing brushless power to the rotor winding set (see Brushless wound-rotor doubly fed electric machine), the active current of the Synchronous WRDF electric machine would be independent of the reactive impedance of the transformer circuit and bursts of torque significantly higher than the maximum operating torque and far beyond the practical capability of any other type of electric machine would be realizable. Torque bursts greater than eight times operating torque have been calculated.

Continuous Torque Density
The continuous torque density of conventional electric machines is determined by the size of the air-gap area and the back-iron depth, which are determined by the power rating of the armature winding set, the speed of the machine, and the achievable air-gap flux density before core saturation. Despite the high coercivity of neodymium or samarium-cobalt permanent magnets, continuous torque density is virtually the same amongst electric machines with optimally designed armature winding sets.

Continuous torque density should never be confused with peak torque density, which comes with the manufacturer's chosen method of cooling, which is available to all, or period of operation before destruction by overheating of windings or even permanent magnet damage.



LINEAR MOTOR

Electric Induction Motor that produces Straight-Line motion by means of a Linear Stator and Rotor placed in Parallel

Section 10 – Electrical Motors Post Quiz

Motor Starters

1. All electric motors, except very large ones are equipped with starters, either full voltage or reduced voltage.
A. True B. False

2. Motors draw a much higher current when they are?

D-C Motors

3. The important characteristic of the D-C motor is that its speed will not vary with the amount of current used.
A. True B. False

4. There are many different kinds of D-C motors, depending on how they are wound and their totally enclosed motors.
A. True B. False

A-C Motors

5. The synchronous type of A-C motor is used in smaller horsepower sizes, usually above 100 HP.
A. True B. False

6. There are a number of different types of alternating current motors, such as Synchronous, Induction, wound rotor, and?

7. Which term of the A-C motor requires complex control equipment, since they use a combination of A-C and D-C.

8. The induction type motor uses only alternating current.
A. True B. False

9. The squirrel cage motor provides a relatively constant speed.
A. True B. False

10. The wound rotor type could be used as a?

Section 10 – Electrical Motors Post Quiz
1. False
2. Starting and gaining speed
3. False
4. False
5. False
6. Squirrel cage
7. Synchronous type
8. True
9. True
10. Variable speed motor

Energy Glossary

Ampere: The unit of measurement of electrical current produced in a circuit by 1 volt acting through a resistance of 1 Ohm.

Ancillary services: Services that ensure reliability and support the transmission of electricity from generation sites to customer loads. Such services may include load regulation, spinning reserve, non-spinning reserve, replacement reserve, and voltage support.

Apparent power: The product of the voltage (in volts) and the current (in amperes). It comprises both active and reactive power. It is measured in "volt-amperes" and often expressed in "kilovolt-amperes" (kVA) or "megavolt-amperes" (MVA).

Ash: Impurities consisting of silica, iron, alumina, and other noncombustible matter that are contained in coal. Ash increases the weight of coal, adds to the cost of handling, and can affect its burning characteristics Ash content is measured as a percent by weight of coal on an "as received" or a "dry" (moisture-free, usually part of a laboratory analysis) basis.

Available but not needed capability: Net capability of main generating units that are operable but not considered necessary to carry load and cannot be connected to load within 30 minutes.

Average revenue per kilowatt-hour: The average revenue per kilowatt-hour of electricity sold by sector (residential, commercial, industrial, or other) and geographic area (State, Census division, and national) is calculated by dividing the total monthly revenue by the corresponding total monthly sales for each sector and geographic area.

Balancing authority (electric): The responsible entity that integrates resource plans ahead of time, maintains load-interchange-generation balance within a Balancing Authority Area, and supports Interconnection frequency in real time. NERC definition

Barrel: A unit of volume equal to 42 U.S. gallons.

Base load: The minimum amount of electric power delivered or required over a given period of time at a steady rate.

Base load capacity: The generating equipment normally operated to serve loads on an around-the-clock basis.

Base load plant: A plant, usually housing high-efficiency steam-electric units, which is normally operated to take all or part of the minimum load of a system, and which consequently produces electricity at an essentially constant rate and runs continuously. These units are operated to maximize system mechanical and thermal efficiency and minimize system operating costs.

bbl: The abbreviation for barrel(s).

bcf: The abbreviation for billion cubic feet.

Bilateral agreement: A written statement signed by two parties that specifies the terms for exchanging energy.

Bilateral energy transaction: A transaction between two willing parties who enter into a physical or financial agreement to trade energy commodities. Bilateral transactions entail reciprocal obligations and can involve direct negotiations or deals made through brokers.

Biomass: Organic non-fossil material of biological origin constituting a renewable energy source.

Bituminous coal: A dense coal, usually black, sometimes dark brown, often with well-defined bands of bright and dull material, used primarily as fuel in steam-electric power generation, with substantial quantities also used for heat and power applications in manufacturing and to make coke. Bituminous coal is the most abundant coal in active U.S. mining regions. Its moisture content usually is less than 20 percent. The heat content of bituminous coal ranges from 21 to 30 million Btu per ton on a moist, mineral-matter-free basis. The heat content of bituminous coal consumed in the United States averages 24 million Btu per ton, on the as-received basis (i.e., containing both inherent moisture and mineral matter).

Boiler: A device for generating steam for power, processing, or heating purposes; or hot water for heating purposes or hot water supply. Heat from an external combustion source is transmitted to a fluid contained within the tubes found in the boiler shell. This fluid is delivered to an end-use at a desired pressure, temperature, and quality.

British thermal unit: The quantity of heat required to raise the temperature of 1 pound of liquid water by 1 degree Fahrenheit at the temperature at which water has its greatest density (approximately 39 degrees Fahrenheit).

Bundled utility service (electric): A means of operation whereby energy, transmission, and distribution services, as well as ancillary and retail services, are provided by one entity.

Capacity: See Generator capacity and (installed) Generator name plate capacity.

Capacity (purchased): The amount of energy and capacity available for purchase from outside the system.

Capacity charge: An element in a two-part pricing method used in capacity transactions (energy charge is the other element). The capacity charge, sometimes called Demand Charge, is assessed on the amount of capacity being purchased.

Circuit: A conductor or a system of conductors through which electric current flows.

Coal: A readily combustible black or brownish-black rock whose composition, including inherent moisture, consists of more than 50 percent by weight and more than 70 percent by volume of carbonaceous material. It is formed from plant remains that have been compacted, hardened, chemically altered, and metamorphosed by heat and pressure over geologic time.

Coal synfuel: Coal-based solid fuel that has been processed by a coal synfuel plant; and coal-based fuels such as briquettes, pellets, or extrusions, which are formed from fresh or recycled coal and binding materials.

Cogenerator: A generating facility that produces electricity and another form of useful thermal energy (such as heat or steam), used for industrial, commercial, heating, or cooling purposes.

To receive status as a qualifying facility (QF) under the Public Utility Regulatory Policies Act (PURPA), the facility must produce electric energy and "another form of useful thermal energy through the sequential use of energy" and meet certain ownership, operating, and efficiency criteria established by the Federal Energy Regulatory Commission (FERC).(See the Code of Federal Regulations, Title 18, Part 292.)

Coincidental demand: The sum of two or more demands that occur in the same time interval.

Coincidental peak load: The sum of two or more peak loads that occur in the same time interval.

Coke (petroleum): A residue high in carbon content and low in hydrogen that is the final product of thermal decomposition in the condensation process in cracking. This product is reported as marketable coke or catalyst coke. The conversion is 5 barrels (of 42 U.S. gallons each) per short ton. Coke from petroleum has a heating value of 6.024 million Btu per barrel.

Combined cycle: An electric generating technology in which electricity is produced from otherwise lost waste heat exiting from one or more gas (combustion) turbines. The exiting heat is routed to a conventional boiler or to a heat recovery steam generator for utilization by a steam turbine in the production of electricity. This process increases the efficiency of the electric generating unit.

Combined cycle unit: An electric generating unit that consists of one or more combustion turbines and one or more boilers with a portion of the required energy input to the boiler(s) provided by the exhaust gas of the combustion turbine(s).

Combined heat and power (CHP) plant: A plant designed to produce both heat and electricity from a single heat source. Note: This term is being used in place of the term "cogenerator" that was used by EIA in the past. CHP better describes the facilities because some of the plants included do not produce heat and power in a sequential fashion and, as a result, do not meet the legal definition of cogeneration specified in the Public Utility Regulatory Policies Act (PURPA).

Combined pumped-storage plant: A pumped-storage hydroelectric power plant that uses both pumped water and natural stream flow to produce electricity.

Competitive transition charge: A non-bypassable charge levied on each customer of the distribution utility, including those who are served under contracts with nonutility suppliers, for recovery of the utility's stranded costs that develop because of competition.

Congestion: A condition that occurs when insufficient transfer capacity is available to implement all of the preferred schedules for electricity transmission simultaneously.

Conservation: A reduction in energy consumption that corresponds with a reduction in service demand. Service demand can include buildings-sector end uses such as lighting, refrigeration, and heating; industrial processes; or vehicle transportation. Unlike energy efficiency, which is typically a technological measure, conservation is better associated with behavior. Examples of conservation include adjusting the thermostat to reduce the output of a heating unit, using occupancy sensors that turn off lights or appliances, and car-pooling.

Cooperative electric utility: An electric utility legally established to be owned by and operated for the benefit of those using its service. The utility company will generate, transmit, and/or distribute supplies of electric energy to a specified area not being serviced by another utility. Such ventures are generally exempt from Federal income tax laws. Most electric cooperatives have been initially financed by the Rural Utilities Service (prior Rural Electrification Administration), U.S. Department of Agriculture.

Cost-based rates (electric): A ratemaking concept used for the design and development of rate schedules to ensure that the fixed rate schedules recover only the cost of providing the service. FERC definition

Cost-of-service regulation: A traditional electric utility regulation under which a utility is allowed to set rates based on the cost of providing service to customers and the right to earn a limited profit.

Current (electric): A flow of electrons in an electrical conductor. The strength or rate of movement of the electricity is measured in amperes.

Customer choice: The right of customers to purchase energy from a supplier other than their traditional supplier or from more than one seller in the retail market.

Day-ahead schedule: A schedule prepared by a scheduling coordinator or the independent system operator before the beginning of a trading day. This schedule indicates the levels of generation and demand scheduled for each settlement period that trading day.

Demand bid: A bid into the power exchange indicating a quantity of energy or an ancillary service that an eligible customer is willing to purchase and, if relevant, the maximum price that the customer is willing to pay.

Derate: A decrease in the available capacity of an electric generating unit, commonly due to:
• A system or equipment modification
• Environmental, operational, or reliability considerations. Causes of generator capacity deratings include high cooling water temperatures, equipment degradation, and historical performance during peak demand periods. In this context, a derate is typically temporary and due to transient conditions. The term derate can also refer to discounting a portion of a generating units capacity for planning purposes.

Deregulation: The elimination of some or all regulations from a previously regulated industry or sector of an industry.

Diesel fuel: A fuel composed of distillates obtained in petroleum refining operation or blends of such distillates with residual oil used in motor vehicles. The boiling point and specific gravity are higher for diesel fuels than for gasoline.

Direct access: The ability of a retail customer to purchase electricity or other energy sources directly from a supplier other than their traditional supplier.

Distribution: The delivery of energy to retail customers.

Distribution provider (electric): Provides and operates the ¿wires¿ between the transmission system and the end-use customer. For those end-use customers who are served at transmission voltages, the Transmission Owner also serves as the Distribution Provider. Thus, the Distribution Provider is not defined by a specific voltage, but rather as performing the Distribution function at any voltage. NERC definition

Distribution system: The portion of the transmission and facilities of an electric system that is dedicated to delivering electric energy to an end-user.

Divestiture: The stripping off of one utility function from the others by selling (spinning-off) or in some other way changing the ownership of the assets related to that function. Stripping off is most commonly associated with spinning-off generation assets so they are no longer owned by the shareholders that own the transmission and distribution assets.

Electric industry restructuring: The process of replacing a monopolistic system of electric utility suppliers with competing sellers, allowing individual retail customers to choose their supplier but still receive delivery over the power lines of the local utility. It includes the reconfiguration of vertically-integrated electric utilities.

Electric plant (physical): A facility containing prime movers, electric generators, and auxiliary equipment for converting mechanical, chemical, and/or fission energy into electric energy.

Electric rate schedule: A statement of the electric rate and the terms and conditions governing its application, including attendant contract terms and conditions that have been accepted by a regulatory body with appropriate oversight authority.

Electric utility: A corporation, person, agency, authority, or other legal entity or instrumentality aligned with distribution facilities for delivery of electric energy for use primarily by the public. Included are investor-owned electric utilities, municipal and State utilities, Federal electric utilities, and rural electric cooperatives. A few entities that are tariff based and corporately aligned with companies that own distribution facilities are also included.

Electricity: A form of energy characterized by the presence and motion of elementary charged particles generated by friction, induction, or chemical change.

Electricity broker: An entity that arranges the sale and purchase of electric energy, the transmission of electricity, and/or other related services between buyers and sellers but does not take title to any of the power sold.

Electricity congestion: A condition that occurs when insufficient transmission capacity is available to implement all of the desired transactions simultaneously.

Electricity demand: The rate at which energy is delivered to loads and scheduling points by generation, transmission, and distribution facilities.

Electricity demand bid: A bid into the power exchange indicating a quantity of energy or an ancillary service that an eligible customer is willing to purchase and, if relevant, the maximum price that the customer is willing to pay.

Electricity generation: The process of producing electric energy or the amount of electric energy produced by transforming other forms of energy, commonly expressed in kilowatthours(kWh) or megawatthours (MWh).

Electricity only plant: A plant designed to produce electricity only. See also Combined heat and power (CHP) plant.

Electricity paid by household: The household paid the electric utility company directly for all household uses of electricity (such as water heating, space heating, air-conditioning, cooking, lighting, and operating appliances.) Bills paid by a third party are not counted as paid by the household.

Electricity sales: The amount of kilowatt-hours sold in a given period of time; usually grouped by classes of service, such as residential, commercial, industrial, and other. "Other" sales include sales for public street and highway lighting and other sales to public authorities, sales to railroads and railways, and interdepartmental sales.

Energy charge: That portion of the charge for electric service based upon the electric energy (kWh) consumed or billed.

Energy conservation features: This includes building shell conservation features, HVAC conservation features, lighting conservation features, any conservation features, and other conservation features incorporated by the building. However, this category does not include any demand-side management (DSM) program participation by the building. Any DSM program participation is included in the DSM Programs.

Energy deliveries: Energy generated by one electric utility system and delivered to another system through one or more transmission lines.

Energy Efficiency: A ratio of service provided to energy input (e.g., lumens to watts in the case of light bulbs). Services provided can include buildings-sector end uses such as lighting, refrigeration, and heating: industrial processes; or vehicle transportation. Unlike conservation, which involves some reduction of service, energy efficiency provides energy reductions without sacrifice of service. May also refer to the use of technology to reduce the energy needed for a given purpose or service.

Energy efficiency, Electricity: Refers to programs that are aimed at reducing the energy used by specific end-use devices and systems, typically without affecting the services provided. These programs reduce overall electricity consumption (reported in megawatt hours), often without explicit consideration for the timing of program-induced savings. Such savings are generally achieved by substituting technologically more advanced equipment to produce the same level of end-use services (e.g. lighting, heating, motor drive) with less electricity. Examples include high-efficiency appliances, efficient lighting programs, high-efficiency heating, ventilating and air conditioning (HVAC) systems or control modifications, efficient building design, advanced electric motor drives, and heat recovery systems.

Energy Intensity: A ratio of energy consumption to another metric, typically national gross domestic product in the case of a country's energy intensity. Sector-specific intensities may refer to energy consumption per household, per unit of commercial floorspace, per dollar value industrial shipment, or another metric indicative of a sector. Improvements in energy intensity include energy efficiency and conservation as well as structural factors not related to technology or behavior.

Energy Policy Act of 1992 (EPACT): This legislation creates a new class of power generators, exempt wholesale generators, that are exempt from the provisions of the Public Holding Company Act of 1935 and grants the authority to the Federal Energy Regulatory Commission to order and condition access by eligible parties to the interconnected transmission grid.

Energy receipts: Energy brought into a site from another location.

Energy service provider: An energy entity that provides service to a retail or end-use customer.

Energy source: Any substance or natural phenomenon that can be consumed or transformed to supply heat or power. Examples include petroleum, coal, natural gas, nuclear, biomass, electricity, wind, sunlight, geothermal, water movement, and hydrogen in fuel cells.

Exchange energy: See exchange, electricity.

Firm power: Power or power-producing capacity, intended to be available at all times during the period covered by a guaranteed commitment to deliver, even under adverse conditions.

Flue-gas particulate collector: Equipment used to remove fly ash from the combustion gases of a boiler plant before discharge to the atmosphere. Particulate collectors include electrostatic precipitators, mechanical collectors (cyclones), fabric filters (baghouses), and wet scrubbers.

Fly ash: Particulate matter mainly from coal ash in which the particle diameter is less than 1 x 104 meter. This ash is removed from the flue gas using flue gas particulate collectors such as fabric filters and electrostatic precipitators.

Forced outage: The shutdown of a generating unit, transmission line, or other facility for emergency reasons or a condition in which the generating equipment is unavailable for load due to unanticipated breakdown.

Fossil fuel: An energy source formed in the Earth's crust from decayed organic material. The common fossil fuels are petroleum, coal, and natural gas.

Fossil fuel plant: A plant using coal, petroleum, or gas as its source of energy.

Fuel expenses: These costs include the fuel used in the production of steam or driving another prime mover for the generation of electricity. Other associated expenses include unloading the shipped fuel and all handling of the fuel up to the point where it enters the first bunker, hopper, bucket, tank, or holder in the boiler-house structure.

Full forced outage: The net capability of main generating units that are unavailable for load for emergency reasons.

Gas: A non-solid, non-liquid combustible energy source that includes natural gas, coke-oven gas, blast-furnace gas, and refinery gas.

Gas turbine plant: A plant in which the prime mover is a gas turbine. A gas turbine consists typically of an axial-flow air compressor and one or more combustion chambers where liquid or gaseous fuel is burned and the hot gases are passed to the turbine and where the hot gases expand drive the generator and are then used to run the compressor.

Generating unit: Any combination of physically connected generators, reactors, boilers, combustion turbines, and other prime movers operated together to produce electric power.

Generation: The process of producing electric energy by transforming other forms of energy; also, the amount of electric energy produced, expressed in kilowatt-hours.

Generation company: An entity that owns or operates generating plants. The generation company may own the generation plants or interact with the short-term market on behalf of plant owners.

Generator capacity: The maximum output, commonly expressed in megawatts (MW), that generating equipment can supply to system load, adjusted for ambient conditions.

Generator nameplate capacity (installed): The maximum rated output of a generator, prime mover, or other electric power production equipment under specific conditions designated by the manufacturer. Installed generator nameplate capacity is commonly expressed in megawatts (MW) and is usually indicated on a nameplate physically attached to the generator.

Geothermal energy: Hot water or steam extracted from geothermal reservoirs in the earth's crust. Water or steam extracted from geothermal reservoirs can be used for geothermal heat pumps, water heating, or electricity generation.

Geothermal plant: A plant in which the prime mover is a steam turbine. The turbine is driven either by steam produced from hot water or by natural steam that derives its energy from heat found in rock.

Gigawatt (GW): One billion watts or one thousand megawatts.

Gigawatthour (GWh): One billion watthours.

Greenhouse effect: The result of water vapor, carbon dioxide, and other atmospheric gases trapping radiant (infrared) energy, thereby keeping the earth's surface warmer than it would otherwise be. Greenhouse gases within the lower levels of the atmosphere trap this radiation, which would otherwise escape into space, and subsequent re-radiation of some of this energy back to the Earth maintains higher surface temperatures than would occur if the gases were absent.

Grid: The layout of an electrical distribution system. See electric power grid.

Gross generation: The total amount of electric energy produced by generating units and measured at the generating terminal in kilowatthours (kWh) or megawatthours (MWh).

Heat content: The amount of heat energy available to be released by the transformation or use of a specified physical unit of an energy form (e.g., a ton of coal, a barrel of oil, a kilowatthour of electricity, a cubic foot of natural gas, or a pound of steam).

Hydroelectric power: The use of flowing water to produce electrical energy.

Hydrogen: The lightest of all gases, occurring chiefly in combination with oxygen in water; exists also in acids, bases, alcohols, petroleum, and other hydrocarbons.

Implied heat rate: A calculation of the day-ahead electric price divided by the day-ahead natural gas price. Implied heat rate is also known as the 'break-even natural gas market heat rate,' because only a natural gas generator with an operating heat rate (measure of unit efficiency) below the implied heat rate value can make money by burning natural gas to generate power. Natural gas plants with a higher operating heat rate cannot make money at the prevailing electricity and natural gas prices.

Independent power producer: A corporation, person, agency, authority, or other legal entity or instrumentality that owns or operates facilities for the generation of electricity for use primarily by the public, and that is not an electric utility.

Interchange (electric): Energy transfers that cross Balancing Authority boundaries. NERC definition

Interchange authority (electric): The responsible entity that authorizes implementation of valid and balanced Interchange Schedules between Balancing Authority Areas, and ensures communication of Interchange information for reliability assessment purposes. NERC definition

Interchange transaction (electric): An agreement to transfer energy from a seller to a buyer that crosses one or more Balancing Authority Area boundaries. NERC definition

Interdepartmental service (electric): Interdepartmental service includes amounts charged by the electric department at tariff or other specified rates for electricity supplied by it to other utility departments.

Intermediate load (electric system): The range from base load to a point between base load and peak. This point may be the midpoint, a percent of the peak load, or the load over a specified time period.

Internal combustion plant: A plant in which the prime mover is an internal combustion engine. An internal combustion engine has one or more cylinders in which the process of combustion takes place, converting energy released from the rapid burning of a fuel-air mixture into mechanical energy. Diesel or gas-fired engines are the principal types used in electric plants. The plant is usually operated during periods of high demand for electricity.

Interruptible gas: Gas sold to customers with a provision that permits curtailment or cessation of service at the discretion of the distributing company under certain circumstances, as specified in the service contract.

Interruptible load: This Demand-Side Management category represents the consumer load that, in accordance with contractual arrangements, can be interrupted at the time of annual peak load by the action of the consumer at the direct request of the system operator. This type of control usually involves large-volume commercial and industrial consumers. Interruptible Load does not include Direct Load Control.

Interruptible load or interruptible demand (electric): Demand that the end-use customer makes available to its Load-Serving Entity via contract or agreement for curtailment NERC definition

Investor-owned utility (IOU): A privately-owned electric utility whose stock is publicly traded. It is rate regulated and authorized to achieve an allowed rate of return.

Kilowatt (kW): One thousand watts.

Kilowatt-hour (kWh): A measure of electricity defined as a unit of work or energy, measured as 1 kilowatt (1,000watts) of power expended for 1 hour. One kWh is equivalent to 3,412 Btu.

Lignite: The lowest rank of coal, often referred to as brown coal, used almost exclusively as fuel for steam-electric power generation. It is brownish-black and has a high inherent moisture content, sometimes as high as 45 percent The heat content of lignite ranges from 9 to 17 million Btu per ton on a moist, mineral-matter-free basis. The heat content of lignite consumed in the United States averages 13 million Btu per ton, on the as-received basis (i.e. containing both inherent moisture and mineral matter).

Load (electric): An end-use device or customer that receives power from the electric system.

Load-serving entity (electric): Secures energy and transmission service (and related Interconnect Operations Services) to serve the electrical demand and energy requirements of its end-use customers. See NERC definition.

Manufactured gas: A gas obtained by destructive distillation of coal or by the thermal decomposition of oil, or by the reaction of steam passing through a bed of heated coal or coke. Examples are coal gases, coke oven gases, producer gas, blast furnace gas, blue (water) gas, carbureted water gas. Btu content varies widely.

Maximum demand: The greatest of all demands of the load that has occurred within a specified period of time.

Megawatt (MW): One million watts of electricity.

Mega-watthour (MWh): One thousand kilowatt-hours or 1million watt-hours.
Native gas: Gas in place at the time that a reservoir was converted to use as an underground storage reservoir in contrast to injected gas volumes.

Native load (electric): The end-use customers that the Load-Serving Entity is obligated to serve. NERC definition

Net generation: The amount of gross generation less the electrical energy consumed at the generating station(s) for station service or auxiliaries. Note: Electricity required for pumping at pumped-storage plants is regarded as electricity for station service and is deducted from gross generation.

Non-coincidental peak load: The sum of two or more peak loads on individual systems that do not occur in the same time interval. Meaningful only when considering loads within a limited period of time, such as a day, week, month, a heating or cooling season, and usually for not more than 1 year.

Nuclear electric power (nuclear power): Electricity generated by the use of the thermal energy released from the fission of nuclear fuel in a reactor.

Nuclear fuel: Fissionable materials that have been enriched to such a composition that, when placed in a nuclear reactor, will support a self-sustaining fission chain reaction, producing heat in a controlled manner for process use.

Off peak gas: Gas that is to be delivered and taken on demand when demand is not at its peak.

Ohm: A measure of the electrical resistance of a material equal to the resistance of a circuit in which the potential difference of 1 volt produces a current of 1 ampere.

Operable nuclear unit (foreign): A nuclear generating unit outside the United States that generates electricity for a grid.

Other generation: Electricity originating from these sources biomass, fuel cells, geothermal heat, solar power, waste, wind, and wood.

Outage: The period during which a generating unit, transmission line, or other facility is out of service.

Peak demand: The maximum load during a specified period of time.

Peak load plant: A plant usually housing old, low-efficiency steam units, gas turbines, diesels, or pumped-storage hydroelectric equipment normally used during the peak-load periods.

Peaking capacity: Capacity of generating equipment normally reserved for operation during the hours of highest daily, weekly, or seasonal loads. Some generating equipment may be operated at certain times as peaking capacity and at other times to serve loads on an around-the-clock basis.

Percent difference: The relative change in a quantity over a specified time period. It is calculated as follows: the current value has the previous value subtracted from it; this new number is divided by the absolute value of the previous value; then this new number is multiplied by 100.

Petroleum: A broadly defined class of liquid hydrocarbon mixtures. Included are crude oil, lease condensate, unfinished oils, refined products obtained from the processing of crude oil, and natural gas plant liquids. Note: Volumes of finished petroleum products include non-hydrocarbon compounds, such as additives and detergents, after they have been blended into the products.

Petroleum coke: See Coke (petroleum).

Planned generator: A proposal by a company to install electric generating equipment at an existing or planned facility or site. The proposal is based on the owner having obtained either (1) all environmental and regulatory approvals, (2) a signed contract for the electric energy, or (3) financial closure for the facility.

Planning authority (electric): The responsible entity that coordinates and integrates transmission facility and service plans, resource plans, and protection systems. NERC definition

Plant: A term commonly used either as a synonym for an industrial establishment or a generating facility or to refer to a particular process within an establishment.

Plant use: The electric energy used in the operation of a plant. Included is the energy required for pumping at pump-storage plants.

Plant-use electricity: The electric energy used in the operation of a plant. This energy total is subtracted from the gross energy production of the plant.

Power: The rate of producing, transferring, or using energy, most commonly associated with electricity. Power is measured in watts and often expressed in kilowatts (kW) or megawatts (mW). Also known as "real" or "active" power.

Power exchange: An entity providing a competitive spot market for electric power through day- and/or hour-ahead auction of generation and demand bids.

Power exchange generation: Generation scheduled by the power exchange. See definition for power exchange.

Power exchange load: Load that has been scheduled by the power exchange and is received through the use of transmission or distribution facilities owned by participating transmission owners.

Power marketers: Business entities engaged in buying and selling electricity. Power marketers do not usually own generating or transmission facilities. Power marketers, as opposed to brokers, take ownership of the electricity and are involved in interstate trade. These entities file with the Federal Energy Regulatory Commission (FERC) for status as a power marketer.

Power pool: An association of two or more interconnected electric systems having an agreement to coordinate operations and planning for improved reliability and efficiencies.

Power production plant: All the land and land rights, structures and improvements, boiler or reactor vessel equipment, engines and engine-driven generator, turbo generator units, accessory electric equipment, and miscellaneous power plant equipment are grouped together for each individual facility.

Prime mover: The engine, turbine, water wheel, or similar machine that drives an electric generator; or, for reporting purposes, a device that converts energy to electricity directly (e.g., photovoltaic solar and fuel cells).

Production: See production terms associated with specific energy types.

Propane (C_3H_8): A straight-chain saturated (paraffinic) hydrocarbon extracted from natural gas or refinery gas streams, which is gaseous at standard temperature and pressure. It is a colorless gas that boils at a temperature of -44 degrees Fahrenheit. It includes all products designated in ASTM Specification D1835 and Gas Processors Association specifications for commercial (HD-5) propane.

Public authority service to public authorities: Public authority service includes electricity supplied and services rendered to municipalities or divisions or agencies of State or Federal governments under special contracts, agreements, or service classifications applicable only to public authorities.

Public street and highway lighting: Electricity supplied and services rendered for the purpose of lighting streets, highways, parks, and other public places; or for traffic or other signal system service, for municipalities or other divisions or agencies of State or Federal governments.

Public Utility Regulatory Policies Act of 1978: The Public Utility Regulatory Policies Act of1978, passed by the U.S. Congress. This statute requires States to implement utility conservation programs and create special markets for co-generators and small producers who meet certain standards, including the requirement that States set the prices and quantities of power the utilities must buy from such facilities.

Pumped-storage hydroelectric plant: A plant that usually generates electric energy during peak load periods by using water previously pumped into an elevated storage reservoir during off-peak periods when excess generating capacity is available to do so. When additional generating capacity is needed, the water can be released from the reservoir through a conduit to turbine generators located in a power plant at a lower level.

Purchased power adjustment: A clause in a rate schedule that provides for adjustments to the bill when energy from another electric system is acquired and its cost varies from a specified unit base amount.

Pure pumped-storage hydroelectric plant: A plant that produces power only from water that has previously been pumped to an upper reservoir.

Qualifying facility (QF): A cogeneration or small power production facility that meets certain ownership, operating, and efficiency criteria established by the Federal Energy Regulatory Commission (FERC) pursuant to the Public Utility Regulatory Policies Act (PURPA). Railroad and railway electric service: Electricity supplied to railroads and interurban and street railways, for general railroad use, including the propulsion of cars or locomotives, where such electricity is supplied under separate and distinct rate schedules.

Rate base: The value of property upon which a utility is permitted to earn a specified rate of return as established by a regulatory authority. The rate base generally represents the value of property used by the utility in providing service and may be calculated by any one or a combination of the following accounting methods: fair value, prudent investment, reproduction cost, or original cost. Depending on which method is used, the rate base includes cash, working capital, materials and supplies, deductions for accumulated provisions for depreciation, contributions in aid of construction, customer advances for construction, accumulated deferred income taxes, and accumulated deferred investment tax credits.

Rate base (electric): The value of property, upon which, a utility is permitted to earn a specified rate of return as established by a regulatory authority. See FERC definition.

Ratemaking authority: A utility commission's legal authority to fix, modify, approve, or disapprove rates as determined by the powers given the commission by a State or Federal legislature.

Reactive power: The portion of electricity that establishes and sustains the electric and magnetic fields of alternating-current equipment. Reactive power must be supplied to most types of magnetic equipment, such as motors and transformers. Reactive power is provided by generators, synchronous condensers, or electrostatic equipment such as capacitors and directly influences electric system voltage. It is a derived value equal to the vector difference between the apparent power and the real power. It is usually expressed as kilovolt-amperes reactive (KVAR) or megavolt-ampere reactive (MVAR). See Apparent Power, Power, Real Power.

Real Power: The component of electric power that performs work, typically measured in kilowatts (kW) or megawatts(MW)--sometimes referred to as Active Power. The terms "real" or "active" are often used to modify the base term "power" to differentiate it from Reactive Power and Apparent Power. See Apparent Power, Power, Reactive Power.

Regional Transmission Group: A utility industry concept that the Federal Energy Regulatory Commission (FERC) embraced for the certification of voluntary groups that would be responsible for transmission planning and use on a regional basis.
Regulation: The governmental function of controlling or directing economic entities through the process of rulemaking and adjudication.

Reliability coordinator (electric): The entity that is the highest level of authority who is responsible for the reliable operation of the Bulk Electric System, has the Wide Area view of the Bulk Electric System, and has the operating tools, processes and procedures, including the authority to prevent or mitigate emergency operating situations in both next-day analysis and real-time operations. The Reliability Coordinator has the purview that is broad enough to enable the calculation of Interconnection Reliability Operating Limits, which may be based on the operating parameters of transmission systems beyond any Transmission Operators vision. See NERC definition.

Reregulation: The design and implementation of regulatory practices to be applied to the remaining regulated entities after restructuring of the vertically-integrated electric utility. The remaining regulated entities would be those that continue to exhibit characteristics of a natural monopoly, where imperfections in the market prevent the realization of more competitive results, and where, in light of other policy considerations, competitive results are unsatisfactory in one or more respects. Regulation could employ the same or different regulatory practices as those used before restructuring.

Reserve margin (operating): The amount of unused available capability of an electric power system (at peak load for a utility system) as a percentage of total capability.

Residential/commercial (consumer category): Housing units, wholesale or retail businesses (except coal wholesale dealers); health institutions (hospitals, social and educational institutions (schools and universities); and Federal, state, and local governments (military installations, prisons, office buildings, etc.). Excludes shipments to Federal power projects, such as TVA, and rural electrification cooperatives, power districts, and state power projects.

Restricted-universe census: This is the complete enumeration of data from a specifically defined subset of entities including, for example, those that exceed a given level of sales or generator nameplate capacity.

Restructuring: The process of replacing a monopoly system of electric utilities with competing sellers, allowing individual retail customers to choose their electricity supplier but still receive delivery over the power lines of the local utility. It includes the reconfiguration of the vertically-integrated electric utility.

Retail sales (electric): Sales made directly to the customer that consumes the energy product.

Retail wheeling: The process of moving electric power from a point of generation across third-party-owned transmission and distribution systems to a retail customer.

Revenue - (electricity): The total amount of money received by an entity from sales of its products and/or services; gains from the sales or exchanges of assets, interest, and dividends earned on investments; and other increases in the owner's equity, except those arising from capital adjustments.

Right-of-way (electric): A corridor of land on which electric lines may be located. The Transmission Owner may own the land in fee, own an easement, or have certain franchise, prescription, or license rights to construct and maintain lines. See NERC definition.

Running and quick-start capability: The net capability of generating units that carry load or have quick-start capability. In general, quick-start capability refers to generating units that can be available for load within a 30-minute period.

Sales for resale: A type of wholesale sales covering energy supplied to other electric utilities, cooperatives, municipalities, and Federal and state electric agencies for resale to ultimate consumers.

Sales for resale (electric): A type of wholesale sales covering energy supplied to other electric utilities, cooperatives, municipalities, and Federal and state electric agencies for resale to ultimate consumers. FERC definition

Scheduled outage: The shutdown of a generating unit, transmission line, or other facility for inspection or maintenance, in accordance with an advance schedule.

Securitization: A proposal for issuing bonds that would be used to buy down existing power contracts or other obligations. The bonds would be repaid by designating a portion of future customer bill payments. Customer bills would be lowered, since the cost of bond payments would be less than the power contract costs that would be avoided.

Securitize: To aggregate contracts into one pool, which then offers shares for sale in the investment market. This strategy diversifies project risks from what they would be if each project were financed individually, thereby reducing the cost of financing.

Short ton: A unit of weight equal to 2,000 pounds.

Small power producer (SPP): Under the Public Utility Regulatory Policies Act (PURPA), a small power production facility (or small power producer) generates electricity using waste, renewable (biomass, conventional hydroelectric, wind and solar, and geothermal) energy as a primary energy source. Fossil fuels can be used, but renewable resource must provide at least 75 percent of the total energy input. (See Code of Federal Regulations, Title 18, Part 292.)
Solar energy: The radiant energy of the sun, which can be converted into other forms of energy, such as heat or electricity.

Spark spread: A measurement of the difference between the price that a generator can obtain from selling one megawatt hour (MWh) of electricity and the cost of the natural gas needed to generate the MWh of electricity. Spark spread is a measure of potential profit for generating electricity on a particular day. A key component in the spark spread equation is the heat rate (measure of efficiency) of the generating unit. A common measure for heat rate used in the trade press is 7,000 Btu/kWh. This heat rate is broadly representative of the efficiency of newer natural gas combined-cycle power plants. (By way of comparison, a plant that has a 50% efficiency rate has a heat rate of 6,824 Btu/kWh.) The most efficient natural gas combined-cycle power plants have heat rates somewhat below the 7,000 Btu/kWh threshold; they can make money even when the implied (breakeven) heat rate is a little below 7,000 Btu/kWh. Conversely, as the level of plant efficiency decreases, the spark spread diminishes—thus, older, less efficient plants have lower spark spreads than those with a heat rate of 7,000 Btu/kWh.

Spinning reserve: That reserve generating capacity running at a zero load and synchronized to the electric system.

Spot purchases: A single shipment of fuel or volumes of fuel purchased for delivery within 1 year. Spot purchases are often made by a user to fulfill a certain portion of energy requirements, to meet unanticipated energy needs, or to take advantage of low-fuel prices.

Stability: The property of a system or element by virtue of which its output will ultimately attain a steady state. The amount of power that can be transferred from one machine to another following a disturbance. The stability of a power system is its ability to develop restoring forces equal to or greater than the disturbing forces so as to maintain a state of equilibrium.

Stability (electric): The ability of an electric system to maintain a state of equilibrium during normal and abnormal conditions or disturbances. NERC definition

Standard Industrial Classification (SIC): Replaced with North American Industry Classification System. See NAICS.

Standby facility: A facility that supports a utility system and is generally running under no-load. It is available to replace or supplement a facility normally in service.

Standby service: Support service that is available as needed to supplement a customer, a utility system, or another utility if a schedule or an agreement authorizes the transaction. The service is not regularly used.

Steam electric power plant (conventional): A plant in which the prime mover is a steam turbine. The steam used to drive the turbine is produced in a boiler where fossil fuels are burned.

Stranded benefits: Benefits associated with regulated retail electric service which may be at risk under open market retail competition. Examples include conservation programs, fuel diversity, reliability of supply, and tax revenues based on utility revenues.

Stranded costs: Costs incurred by a utility which may not be recoverable under market-based retail competition. Examples include undepreciated generating facilities, deferred costs, and long-term contract costs.

Subbituminous coal: A coal whose properties range from those of lignite to those of bituminous coal and used primarily as fuel for steam-electric power generation. It may be dull, dark brown to black, soft and crumbly, at the lower end of the range, to bright, jet black, hard, and relatively strong, at the upper end. Subbituminous coal contains 20 to 30 percent inherent moisture by weight. The heat content of subbituminous coal ranges from 17 to 24 million Btu per ton on a moist, mineral-matter-free basis. The heat content of subbituminous coal consumed in the United States averages 17 to 18 million Btu per ton, on the as-received basis (i.e., containing both inherent moisture and mineral matter).

Substation: Facility equipment that switches, changes, or regulates electric voltage.

Sulfur: A yellowish nonmetallic element, sometimes known as "brimstone." It is present at various levels of concentration in many fossil fuels whose combustion releases sulfur compounds that are considered harmful to the environment. Some of the most commonly used fossil fuels are categorized according to their sulfur content, with lower sulfur fuels usually selling at a higher price. Note: No.2 Distillate fuel is currently reported as having either a 0.05 percent or lower sulfur level for on-highway vehicle use or a greater than 0.05 percent sulfur level for off-highway use, home heating oil, and commercial and industrial uses. Residual fuel, regardless of use, is classified as having either no more than 1 percent sulfur or greater than 1 percent sulfur. Coal is also classified as being low- sulfur at concentrations of 1 percent or less or high-sulfur at concentrations greater than 1 percent.

Supervisory Control and Data Acquisition (electric): A system of remote control and telemetry used to monitor and control the transmission system. NERC definition

Supplemental gaseous fuels supplies: Synthetic natural gas, propane-air, coke oven gas, refinery gas, biomass gas, air injected for Btu stabilization, and manufactured gas commingled and distributed with natural gas.

Switching station: Facility equipment used to tie together two or more electric circuits through switches. The switches are selectively arranged to permit a circuit to be disconnected or to change the electric connection between the circuits.

System (electric): Physically connected generation, transmission, and distribution facilities operated as an integrated unit under one central management or operating supervision.

System operator (electric): An individual at a control center (Balancing Authority, Transmission Operator, Generator Operator, Reliability Coordinator) whose responsibility it is to monitor and control that electric system in real time. NERC definition

Telemetring (electric): The process by which measurable electrical quantities from substations and generating stations are instantaneously transmitted to the control center, and, by which, operating commands from the control center are transmitted to the substations and generating stations. NERC definition

Terawatthour: One trillion watt hours.

Thermal rating (electric): The maximum amount of electrical current that a transmission line or electrical facility can conduct over a specified time period before it sustains permanent damage by overheating or before it sags to the point that it violates public safety requirements. NERC definition

Tie line (electric): A circuit connecting two Balancing Authority Areas. Also, describes circuits within an individual electrical system. NERC definition

Transformer: An electrical device for changing the voltage of alternating current.

Transmission (electric): An interconnected group of lines and associated equipment for the movement or transfer of electric energy between points of supply and points at which it is transformed for delivery to customers or is delivered to other electric systems. NERC definition

Transmission (electric) (verb): The movement or transfer of electric energy over an interconnected group of lines and associated equipment between points of supply and points at which it is transformed for delivery to consumers or is delivered to other electric systems.
Transmission is considered to end when the energy is transformed for distribution to the consumer.

Transmission constraint (electric): A limitation on one or more transmission elements that may be reached during normal or contingency system operations. NERC definition

Transmission line (electric): A system of structures, wires, insulators and associated hardware that carry electric energy from one point to another in an electric power system. Lines are operated at relatively high voltages varying from 69 kV up to 765 kV, and are capable of transmitting large quantities of electricity over long distances. NERC definition

Transmission operator (electric): The entity responsible for the reliability of its localized transmission system, and that operates or directs the operations of the transmission facilities. NERC definition

Transmission owner (electric): The entity that owns and maintains transmission facilities. NERC definition

Transmission Service Provider (electric): The entity that administers the transmission tariff and provides Transmission Service to Transmission Customers under applicable transmission service agreements. NERC definition

Transmission system (electric): An interconnected group of electric transmission lines and associated equipment for moving or transferring electric energy in bulk between points of supply and points at which it is transformed for delivery over the distribution system lines to consumers or is delivered to other electric systems.

Transmitting utility: A regulated entity which owns and may construct and maintain wires used to transmit wholesale power. It may or may not handle the power dispatch and coordination functions. It is regulated to provide non-discriminatory connections, comparable service, and cost recovery.

Turbine: A machine for generating rotary mechanical power from the energy of a stream of fluid (such as water, steam, or hot gas). Turbines convert the kinetic energy of fluids to mechanical energy through the principles of impulse and reaction, or a mixture of the two.

Ultimate customer: A customer that purchases electricity for its own use and not for resale.

Unbundling: Separating vertically integrated monopoly functions into their component parts for the purpose of separate service offerings.

Uniform system of accounts: Prescribed financial rules and regulations established by the Federal Energy Regulatory Commission for utilities subject to its jurisdiction under the authority granted by the Federal Power Act.

Uprate: An increase in available electric generating unit power capacity due to a system or equipment modification. An uprate is typically a permanent increase in the capacity of a unit.

Useful thermal output: The thermal energy made available in a combined-heat-and-power system for use in any industrial or commercial process, heating or cooling application, or delivered to other end users, i.e., total thermal energy made available for processes and applications other than electrical generation.

Utility distribution companies: The entities that will continue to provide regulated services for the distribution of electricity to customers and serve customers who do not choose direct access. Regardless of where a consumer chooses to purchase power, the customer's current utility, also known as the utility distribution company, will deliver the power to the consumer.

Vertical integration: The combination within a firm or business enterprise of one or more stages of production or distribution. In the electric industry, it refers to the historical arrangement whereby a utility owns its own generating plants, transmission system, and distribution lines to provide all aspects of electric service.

Voltage reduction: Any intentional reduction of system voltage by 3 percent or greater for reasons of maintaining the continuity of service of the bulk electric power supply system.

Volumetric wires charge: See Quantity wires charge.

Waste coal: Usable material that is a byproduct of previous coal processing operations. Waste coal is usually composed of mixed coal, soil, and rock (mine waste). Most waste coal is burned as-is in unconventional fluidized-bed combustors. For some uses, waste coal may be partially cleaned by removing some extraneous noncombustible constituents. Examples of waste coal include fine coal, coal obtained from a refuse bank or slurry dam, anthracite culm, bituminous gob, and lignite waste.

Waste oils and tar: Petroleum-based materials that are worthless for any purpose other than fuel use.

Watt (W): The unit of electrical power equal to one ampere under a pressure of one volt. A Watt is equal to 1/746 horse power.

Watt-hour (Wh): The electrical energy unit of measure equal to one watt of power supplied to, or taken from, an electric circuit steadily for one hour.

Wheeling service: The movement of electricity from one system to another over transmission facilities of interconnecting systems. Wheeling service contracts can be established between two or more systems.

Wholesale competition: A system whereby a distributor of power would have the option to buy its power from a variety of power producers, and the power producers would be able to compete to sell their power to a variety of distribution companies.

Wholesale power market: The purchase and sale of electricity from generators to resellers (who sell to retail customers), along with the ancillary services needed to maintain reliability and power quality at the transmission level.

Wholesale sales: Energy supplied to other electric utilities, cooperatives, municipals, and Federal and state electric agencies for resale to ultimate consumers.

Wholesale transmission services: The transmission of electric energy sold, or to be sold, in the wholesale electric power market.

Wind energy: Kinetic energy present in wind motion that can be converted to mechanical energy for driving pumps, mills, and electric power generators.

Wires charge: A broad term referring to fees levied on power suppliers or their customers for the use of the transmission or distribution wires.

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