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**AMENDMENT RECORD SHEET**

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**3.1 ELECTRON THEORY**

* Structure and distribution of electrical charges within: atoms, molecules, ions compounds;
* Molecular structure of conductors, semiconductors and insulators.

**GENERAL COMPOSITION OF MATTER**

**MATTER**

Matter can be defined as anything that has mass and has and is the substance of which physical objects are composed. Essentially, it is anything that can be touched. Mass is the amount of matter in an given object. Typically, the more matter there is in an object the more mass it will have. Weight is an indirect method of determining mass but not the same. The difference between mass and weight is that weight is determined by how much something or the fixed mass is pulled by gravity. Categories of matter are ordered by molecular activity. The four categories or states are: solids, liquids, gases and plasma. For the purposes of the aircraft technician, only solids, liquids and gases are considered.

**ELEMENTS**

An element is a substance that cannot be reduced to a simpler form by chemical means. Iron, gold, silver, copper, and oxygen are examples of elements. Beyond this point of reduction, the element ceases to be what it is.

**COMPOUNDS**

A compound is a chemical combination of two or more elements. Water is one of the most common compounds and is made up of two hydrogen atoms and one oxygen atom.

**MOLECULES**

The smallest particle of matter that can exist and still retain its identity, such as water (H2O), is called a molecule. A molecule of water is illustrated in figure 1-1. Substances composed of only one type of atom are called elements. But more substances occur in nature as compounds, that is, combination of two or more types of atoms. It would no longer retain the characteristics of water if it work compounded of one atom of hydrogen and two atoms of oxygen. If a drop of water is divided in two and then divided again and again until it cannot be divided any longer, it will still be water.

**ATOMS**

The atom is considered to be the most basic building block of all matter. Atoms are composed of three subatomic particles. These three subatomic particles are: protons, neutrons and electrons. These three particles will determine the properties of specific atoms. Elements are substances composed of the same atoms with specific properties. Oxygen is the example of this.

The main property that defines each element is the number of neutrons, protons, and electrons. Hydrogen and helium are examples of elements. Both of these elements have neutrons, protons, and electrons but differ in the number of those items. This difference alone accounts for the variation in chemical and physical properties of these two different elements. There are over a 100 known elements in the periodic table, and they are categorized according to their properties on that table. The kinetic theory of matter also states that the particles that make up the matter are always moving. Thermal expansion is considered in the kinetic theory and explains why matter contracts when it is cool and expands when it is hot, with the exception of water/ice

**ELECTRONS, PROTONS, AND NEUTRONS**

At the center of the atom is the nucleus, which contains the protons and neutrons. The protons are positively charged particles, and the neutrons are a neutrally charged particle. The neutron has approximately the same mass as the proton. The third particle of the atom is the electron that is a negatively charged particle with the very small mass compared to the proton. The proton’s mass is approximately 1837 times greater than the electron. Due to the proton and the neutron location in the central portion of the atom(nucleus) and the electron’s position at the distant periphery of the atom, it is the electron that undergoes the change during chemical reactions. Since a proton weighs approximately 1845 times as much as an electron, the number of protons and neutrons in its nucleus determines the overall weight of an atom.

The weight of an electron is not considered in determining the weight of an atom. Indeed, the nature of electricity cannot be defined clearly because it is not certain whether the electron is the negative charge with no mass (weight) or a particle of matter with a negative charge.

Hydrogen represents the simplest form of an atom, as shown in figure 1-2. Atthe nucleus of the hydrogen atom is one proton and at the outer shell is one orbiting electron. At a more complex level is the oxygen atom, as shown in figure 1-3, which has eight electrons in two shells orbiting the nucleus with eight protons and eight neutrons. When positive charge of the protons in the nucleus equals the total negative charge of the electrons in orbit around the nucleus, the atom is said to have a neutral charge.

**ELECTRONS SHELLS AND ENERGY LEVELS**

Electrons require a certain amount of energy to stay in an orbit. This particular quantity is called the electron’s energy level. By its motion alone, the electron possesses kinetic energy, while the electron’s position in orbit determines its potential energy. The total energy of an electron is the main factor that determines the radius of the electron’s orbit.

Electrons of an atom will appear only at certain definite energy levels (shells). The spacing between energy levels is such that when the chemical properties of the various elements are cataloged it is convenient to group several closely spaced permissible energy levels together into electron shells. The maximum number of that can be contained in any shell or sub-shell is the same for all atoms and is defined as Electron capacity = 2n2 . In this equation n represents the energy level in question. The first shell can only contain two electrons; the second shell can only contain eight electrons; the third, 18 and so on until we reach the seventh shell for the

heaviest atoms, which have six energy levels. Because the innermost shell is the lowest energy level, the shell begins to fill up from the shell closest to the nucleus and fill outward as the atomic number of the element increases. However, an energy level does not need to be completely filled before electrons begin to fill the next level. The periodic table of elements should be checked to determine an element’s electron configuration.

**VALENCEELECTRONS**

Valence is the number of chemical bonds an atom can form. Valence electrons are electrons that can participate in chemical bonds with other atoms. The number of electrons in the outermost shell of the atom is the determining factor in its valence. Therefore, the electrons contained in this shell are called valence electrons.

**IONS**

Ionization is the process by which an atom loses or gains electrons. Dislodging an electron from an atom will cause the atom to become positively charged. This net positively charged atom is called a positive ion or cation. An atom that has gained an extra number of electrons is negatively charged and is called a negative ion or an anion. When atoms are neutral, the positively charged proton and the negatively charged electrons are equal in number.

**FREE ELECTRONS**

Valence electrons are found drifting midway between two nuclei. Some electrons are more tightly bound to the nucleus of their atom than others and are positioned in a shell or sphere closer to the nucleus, while others are most loosely bound and orbit at a greater distance from the nucleus. These outermost electrons are called “free” electrons because they can be easily dislodged from the positive attraction of the protons in the nucleus. Once freed from the atom, the electron can then travel from atom to atom, becoming the flow of electrons commonly called current in a particle electrical circuit.

**ELECTRON MOVEMENT**

The valence of an atom determines its ability to gain or lose an electron, which ultimately determines the chemical and electrical properties of the atom. These properties can be categorized as being a conductor, semiconductor or insulator, depending on the ability of the material to produce free electrons. When a material has a large number of free electrons available, a greater current can be conducted in the material.

**CONDUCTORS**

Elements such as gold, copper and silver possess many free electrons and make good conductors. The atoms in these materials have a few loosely bound electrons in their outer orbits. Energy in the form of heat can cause these electrons in the outer orbit to break loose and drift throughout the material. Copper and silver have one electron in their outer orbits. At room temperature, a piece of silver wire will have billions of free electrons.

**INSULATORS**

These are materials that do not conduct electrical current very well or not at all. Good examples of these are: glass, ceramic, and plastic. Under normal conditions, atoms in these materials do not produce free electrons. The absence of the free electrons means that electrical current cannot be conducted through the material. Only when the material is in an extremely strong electrical field will the outer electrons be dislodged. This action is called breakdown and usually causes physical damage to the insulator.

**SEMICONDUCTORS**

This material falls in between the characteristics of conductors and insulators, in that they are not good at conducting or insulating. Silicon and germanium are the most widely used semiconductor materials.

**3.2 STATIC ELECTRICITY AND CONDUCTION**

* Static electricity and distribution of electrostatic charges;
* Electrostatic lawsof attraction and repulsion;
* Units of charge, coulomb’s law;
* Conduction of electricity in solids, liquids, gases and a vacuum.

**STATIC ELECTRICITY**

Electricity is often described as being either static or dynamic. The difference between the two is based simply on whether the electrons are at rest (static) or in motion (dynamic). Static electricity is a build up of an electrical charge on the surface of an object. It is considered “static” due to the fact that there is no current flowing as in AC or DC electricity. Static electricity is usually caused when non-conductive materials such as rubber, plastic or glass are rubbed together, causing a transfer of electrons, which then results in an imbalance of charges between the two materials means that the objects will exhibit an attractive or repulsive force.

**ATTRACTIVE AND REPULSIVE FORCES**

One of the most fundamental laws of static electricity, as well as magnetics, deals with attraction and repulsion. Like charges repel each other and unlike charges attract each other. All electrons possess a negative charge and as such will repel each other. Similarly, all protons possess a positive charge and as such will repel each other. Electrons (negative) and protons (positive) are opposite in their charge and will attract each other. For example, if two pith balls are suspended, as shown in figure 2-1, and each ball is touched with the charged glass rod, some of the charge from the rod is transferred to the balls. The balls now have similar charges and, consequently,, repel

each other as shown in part B of figure 2-1. If a plastic rod is rubbed with fur, it becomes negatively charged and the fur is positively charged. By touching each ball with these differently charged sources, the balls obtain opposite charges and attract each other as shown in part C of figure 2-1.

Coulomb’s law further defines the relationship between charges. It states that like charges repel and opposite charges attract with a force proportional to the product of the charges and inversely proportional to the square of the distance between them. This means that objects with greater charge repel similar charges and attract opposite charges with greater force. Also, as the distance between charges becomes greater, the repulsion or attraction between the charges decreases.

**UNITS OF CHARGE**

A single elementary charge (e) is the charge that a single proton (or electron) possesses. The coulomb (C) is an SI derived unit of electrical charge. One coulomb is equal to the electrical charge. One coulomb is equal to the charge carried by one ampere in one second. An ampere represents the flow of 6.241 x 1018 electrons.

Although most objects become charged with static electricity by means of friction, a charged substance can also influence objects near it by contact. This is illustrated in figure 2-2. If a positively charged rod touches an uncharged metal bar, it will draw electrons from the uncharged bar to the point of contact. Some electrons will enter the rod, leaving the metal bar with a deficiency of electrons (positively charged) and making the rod less positive than it was or, perhaps, even neutralizing its charge completely.

A method of charging a metal bar by induction is demonstrated in figure 2-3. A positively charged rod is brought near, but does not touch, an uncharged metal bar. Electrons in the metal bar are attracted to the end of the bar nearest the positively charged rod, leaving a deficiency of electrons at the opposite end of the bar. If this positively charged end is touched by a neutral object, electrons will flow into the metal bar and neutralize the charge. The metal bar is left with an overall excess of electrons.

**ELECTROSTATIC FIELD**

A field of force exists around a charged body. This field is an electrostatic field (sometimes called a dielectric field) and is represented by lines extending in all directions from the charged body and terminating where there is an equal and opposite charge.

To explain the action of an electrostatic field, lines are used to represent the direction and intensity of the electric field is indicated by the number of lines per unit area, and the direction in which a small test charge would move or tend to move if acted upon by the field of force.

Either a positive or negative test charge can be used, but it has been arbitrarily agreed that a small positive charge will always be used in determining the direction of the field. Thus, the direction of the field around a positive charge is always away from the charge, as shown in figure 2-4, because a positive test charge would be repelled. On the other hand, the direction of the lines about a negative charge is toward the charge, since a positive test charge is at attracted toward it.

Figure 2-5 illustrates the field around bodies having like charges. Positive charges are shown, but regardless of the type of charge, the lines of force would repel each other if the charges were alike. The lines terminate on material objects and always extend from a positive charge to a negative charge. These lines are imaginary lines used to show the direction a real force takes

It is important to know how a charge is distributed on an object. Figure 2-6 shows a small metal disk on which a concentrated negative charge has been placed. By using an electrostatic detector, it can be shown that the charge is spread evenly over the entire surface of the disk. Since the metal disk provides uniform resistance everywhere on its surface, the mutual repulsion of electrons will result in an even distribution over the entire surface.

Another example, shown in Figure 2-7, is the charge on a hollow sphere. Although the sphere is made of conducting material, the charge is evenly distributed over the outside surface. The inner surface is completely neutral. This phenomenon is used to safeguard operating personnel of the large. Van de Graff static generators used for atom smashing. The safest area for the operators is inside the large sphere, where millions of volts are being generated.

The distribution of the charge on an irregular shaped object differs from that on a regularly shaped object. Figure 2-8 shows that the charge on such objects is not evenly distributed. The greatest charge is at the points, or areas of sharpest curvature, of the objects.

**ESD CONSIDERATIONS**

One of the most frequent causes damage to a solid state component or integrated circuits is the electrostatic discharge (ESD) from the human body when one of these devices is handled. Careless handling of line replaced units (LRUs), circuit cards, and discrete components can cause unnecessarily time consuming and expensive repairs. This damage can occur if a technician touches the mating pins for a card or box. Others sources for ESD can be the top of a toolbox that is covered with Damage can be avoided by discharging the static electricity from your body by touching the chassis of the removed box, by wearing a grounding wrist strap, and exercising good professional handling of the components in the aircraft. This can include placing protective caps over open connectors and not placing an ESD sensitive component is an environment that will cause damage. Parts that are ESD sensitive are typically shipped in bags specially designed to protest components from electrostatic damage.

Other precautions that should be taken with working with electronic components are:

1. Always connect a ground between test equipment and circuit before attempting to inject or monitor a signal.
2. Ensure test voltages do not exceed maximum allowable voltage for the circuit components and transistors.
3. Ohmmeter ranges that require a current of more than one milliampere in the test circuit should not be used for testing transistors.
4. The heat applied to a diode or transistor, when soldering is required, should be kept to a minimum by using low-wattage soldering irons and heat-sinks.
5. Do not pry components off of a circuit board.
6. Power must be removed from a circuit beforereplacing a component.
7. When using test probes on equipment and the space between the test points is very close, keep the exposed portion of the leads as short as possible to prevent shorting.

**CONDUCTION OF ELECTRICITY**

Electricity can be conducted through solids, liquids, and gases. It can ever pass through a vacuum. Electric current is the movement of valence electrons. Solids, particularly metals, that have valence electrons with weak covalent bonds are excellent conductors. Liquid metals possess the same characteristics. Some non-metallic liquids also conduct electricity by ionization of their molecules.

Water, for example, ionizes when electricity is applied and the ions carry the electric current. Gases are typically good insulators but some gases also ionize and carry current, especially in the presence of a large electromotive force such as lightening. There are no electrons to carry current in a vacuum, however, should electrons be injected into a vacuum, there is nothing to inhibit their movement. As such a vacuum is an ideal conductor.

**3.3 ELECTRICAL TERMINOLOGY**

* The following terms, their units and factors affecting them: potential difference, electromotive force, voltage, current, resistance, conductance, charge, conventional current flow, electron flow.

**SI PREFIXES USED FOR ELECTRICAL CALCULATIONS**

In any system of measurements, a single set of units is usually not sufficient for all the computations involved in electrical repair and maintenance. Small distances, for example, can usually be measured in inches, but larger distances are more meaningfully expressed in 0feet, yards, or miles. Since electrical values often vary from numbers that are a millionth part of a basic unit of measurement to very large values, it is often necessary to use a wide range of numbers to represent with the name of the unit have been devised for the various multiples or sub multiples of the basic units. There are 12 of these prefixes, which are also known as conversion factors.

Four of the most commonly used prefixes used in electrical work with a short definition of each are as follows:

* Mega (M) means one million (1000000)
* Kilo (K) means one thousand (1000)
* Milli (m) means one-thousandth (1/1000)
* Micro (μ) means one- millionth (1/1000000)

One of the most extensively used conversion factors, kilo, can be used to explain the use of prefixes with basic units of measurement. Kilo means 1000, and when used with volts, is expressed as kilovolt, meaning 1000 volts.

The symbol for kilo is the letter “k”. Thus, 1000 volts is one kilovolt or 1kv. Conversely, one volt would equal one-thousandth of a kv, or 1/1000 kv. This could also be written 0.001 kv.

Similarly, the word “milli” means one –thousandth, and thus, 1 millivolt equals one- thousandth (1/1000) of a volt. Figure 3-1 contains a complete list of the multiples used to express electrical quantities, together with the prefixes and symbols used to represent each number.

**NUMBERPREFIXSYMBOL**

* 1000000000000 tera t
* 1000000000 giga g
* 1000000 mega m
* 1000 kilo k
* 100 hecto h
* 10 deka dk
* 0.1 deci d
* 0.01 centi c
* 0.001 milli m
* 0.000001 micro μ
* 0.000000001 nano n
* 0.000000000001 pico p

Figure 3-1 prefixes and symbols for multiples of basic quantities.

**CONVENTIONAL FLOW AND ELECTRONIC FLOW**

Today’s technician will find that there are two competing schools of thought and analytical practices regarding the flow of electricity. The two are called the conventional current theory and the electron theory.

**CONVENTIONAL FLOW**

Of the two, the conventional current theory was the first to be developed and, through many years of use, this method has become ingrained in electrical texts. The theory was initially advanced by Benjamin Franklin who reasoned that current flowed out of a positive source into a negative source or an area that lacked an abundance of charge. The notation assigned to the electric charges was positive (+) for the abundance of charge and negative (-) for a lack of charge. It then seemed natural to visualize the flow of current as being from the positive(+) to the negative(-).

**ELECTRON FLOW**

Later discoveries were made that proved that just the opposite is true. Electron flow is what actually happens where an abundance of electrons flow out of the negative(-) source to an area that lacks electrons or the positive (+)source. Both conventional flow and electron flow are used in industry. Many textbooks in current use employ both electron flow and conventional flow methods. From the practical standpoint of the technician, troubleshooting a system, it makes little to no difference which way current is flowing as long as it is used consistently in the analysis.

**ELECTROMOTIVE FORCE (VOLTAGE)**

Unlike current, which is easy to visualize as a flow, voltageis a variable that is determined between two points. Often we refer to voltage as a value across two points. It is the electromotive force (emf) or the push or pressure felt in a conductor that ultimately moves the electrons in a flow. The symbol for emf is the capital letter “”.

Across the terminals of the typical aircraft battery, voltage can be measured as the potential difference of 12volts or 24 volts. That is to say that between the two terminal posts of the battery, there is an electromotive force of 12 or 24 volts available to push current through a circuit. Relatively free electrons in the negative terminal will move toward the excessive number of positive charges in the positive terminals. Recall from the discussion on static electricity that like charges repel each other but opposite charges attract each other. The net result is a flow or current through a conductor. There cannot be a flow in a conductor unless there is an applied voltage from a battery, generator, or ground power unit. The potential difference, or the voltage across any two points in an electrical system, can be determined by

E=E {\displaystyle {\mathcal {E}}} /QE {\displaystyle {\mathcal {E}}}

Where

E= potential difference in volts

= energy expanded or absorbed in joules(J)

Q= Charged measured in coulombs

Figure 3-2 illustrates the flow of electrons of electric current. Two interconnected water tanks demonstrate that when a difference of pressure exists between the two tanks, water will flow until the two tanks are equalized. The illustration shows the level of water in tank A be at a higher level, reading 10 psi (higher potential energy). Between the two tanks, there is 8-psi potential difference. If the value in the interconnecting line between the tanks is opened, water will flow from tank A into tank B until the level of water (potential energy) of both tanks is equalized.

It is important to note that it was not the pressure in tank A thatcaused the water to flow; rather, it was the difference in pressure between tank A and tank B that caused the flow.

This comparison illustrates the principle that electrons move, when a path is available, from a point of excess electrons (higher potential energy) to a point deficient in electrons (lower potential energy). The force that causes this movement is the potential difference in electrical energy between the two points. This force called the electrical pressure or the potential difference or the electromotive force (electron moving force).

**CURRENT**

Electrons in motion make up an electric current. This electric current is usually referred to as “current” or “current flow”, no matter how many electrons are moving. Current is a measurement of a rate at which a charge flows through some region of space or a conductor.The moving charges are the free electrons found in conductors, such as copper, silver, aluminum, and gold. The term “free electron” describes a condition in some atoms where the outer electrons are loosely bound to their parent atom. This loosely bound electrons can be easily motivated to move in a given direction when an external source,such as a battery, is applied to the circuit.

These electrons are attracted to the positive terminal of the battery, while the negative terminal is the source of the electrons. The greater amount of charge moving through the conductor in a given amount of time translates into a current.

Current= charge/Time

Or

I =Q/t

Where:

I = Current in Amperes (A)

Q =Charge in Coulombs (C)

T = Time

The system International (SI) unit for current is the Ampere (A), where:

1A = 1 C/s

That is 1 ampere (A) of current is equivalent to 1 coulomb (C) of charge passing through a conductor in 1 second(s). One coulomb of charge equals 6.24 billion billion (1018) electrons. The symbol used to indicate current in formulas or on schematics is the capital letter “I”.

When current flow is one direction, it is called direct current (DC). Later in the text, we will discuss the form of current that periodically oscillates back and forth within the circuit. The present discussion will only be concerned with the use of direct current. The velocity of the charge is actually an average velocity and is called drift velocity. To understand the idea of drift velocity, think of a conductor in which the charge carriers are free electrons. These electrons are always in a state of random motion similar to that of

gas molecules. When a voltage is applied across the conductor, an electromotive force creates an electric field within the conductor and a current is established. The electrons do not move in a straight direction but undergo repeated collisions with other near by atoms. These collisions usually knock other free electrons from there atoms, and these electrons move on toward the positive end of the conductor with an average velocity called the drift velocity, which is relatively a slow speed. To understand the nearly instantaneous speed of the effect of the current, it is helpful to visualize a long tube filled with steel balls as shown in Figure 3-3.

It can be seen that the ball introduced in one end of the tube, which represents the conductor, will immediately cause a ball to be emitted at the opposite end of the tube. Thus, electric current can be viewed as instantaneous, even though it is the result of a relatively slow drift of electrons.

**RESISTANCE**

The two fundamental properties of current and voltage are related by a third property known as resistance. In any electrical circuit, when voltage is applied to it a current will result. The resistance of the conductor determines the amount of current that flows under the given voltage. In most cases the greater the circuit resistance, the less the current. If the resistance is reduced, then the current will increase this relation is linear in nature and is known as Ohm’s law.

**3.4 GENERATION OF ELECTRICITY**

* Production of electricity by the following methods: light, heat, friction, pressure, chemical action, magnetism and motion.

**SOURCE OF ELECTRICITY**

Electrical energy can be produced in a number of methods. The four most common are pressure, chemical, thermal and light.

**PRESSURE SOURCE**

This form of electrical generation is commonly known as piezoelectric (piezo or piez taken from greek: to press; pressure; to squeeze) is a result of the application of mechanical pressure on a dielectric or non-conducting crystal. The most common piezoelectric materials used today are crystalline quartz and Rochelle salt. However, Rochelle salt is being superseded by other materials such as barium titanate.

The application of a mechanical stress produces an electric polarization, which is proportional to this stress. This polarization establishes a voltage across a crystal. If a circuit is connected across the crystal a flow of current can be observed when the crystal is loaded (pressure is applied). An opposite condition can occur, where an application of a voltage between certain faces of the crystal can produce a mechanical distortion. This effect iscommonly referred to as the piezoelectric effect.

Piezoelectric materials are used extensively in transducers for converting a mechanical strain into an electrical signal. Such devices include microphones, phonograph pickups and vibrations-sensing elements.

The opposite effect, in which a mechanical output is derived from an electrical signal input, is also widely used in headphones and loudspeakers.

**CHEMICAL SOURCE**

Chemical energy can be converted into electricity; the most common form of this is the battery. A primary battery produces electricity using two different metals in a chemical solution like alkaline electrolyte, where a chemical reaction between the metals and the chemicals frees more electrons in one metal than in the other. One terminal of the battery is attached to one of the metals such as zinc; the other terminal is attached to the other metal such as manganese oxide. The end that frees more electrons develops a positive charge and other end develops a negative charge. If a wire is attached from one end of the battery to the other, electrons flow throw the wire to balance the electrical charge.

**THERMAL SOURCES**

The most common source of thermal electricity found in the aviation industry comes from thermocouples. Thermocouples are widely used as temperature sensors. They are cheap ad interchangeable, have standard connectors, and can measure a wide range of temperatures. Thermo couples are pairs of dissimilar metal wires joined at least atone end, which generate a voltage between the two wires that is proportional to thetemperature at the junction. This is called the seebeck effect, in honor of Thomas seebeck who firstnotice the phenomena in 1821. It was also noticed that different metal combinations have a different voltage difference. Thermocouples are utilized in aviation as ways to measure cylinder head temperatures, inter-turbine temperature and exhaust gas temperature.

**LIGHT SOURCES**

A solar cell or a photovoltaic cell is a device that converts light energy into electricity. Fundamentally, the device contains certain chemical elements that when exposed to light energy, they release electrons. Photons in sunlight are taken in by the solar panel or cell, where they are then observed by semi conducting materials, such as silicon. Electrons in the cell are broken loose from their atoms, allowing them to flow through the material to produce electricity. The complementary positive charges that are also created are called holes(absence of electron) and flow in the direction opposite of the electrons in a silicon solar panel. Solar cells have many applications and have historically been used in earth orbiting satellites or space probes, hand held calculators, and wrist watches.

**FRICTION**

The production of electricity by friction refers to the buildup of static electricity when non-conductive materials are rubbed together. A transfer of electrons occurs resulting in an imbalance of charges between the materials.

**MAGNESTISM AND MOTION**

When a conductor is moved through the magnetic lines of flux created by a magnet or electromagnet, electromotive force is created and current flow produced for use by various electrically operated devices and components.

**3.5 DC SOURCES OF ELECTRICITY**

* Construction and basic chemical action of: primary cells, secondar cells, lead acid cells, nickel cadmium cells, other alkaline cells
* Cells connected in series and parallel; internal resistance and its effect on a battery;
* Construction, materials and operation of thermo couples;
* Operation of photo-cells.

BATTERIES

PRIMARY CELL

The dry cell is the most common type of primary cell battery and is similar in its characteristics to that of an electrolytic cell. This type of a battery is basically designed with a metal electrode or graphite rod acting as the cathode (+) terminal, immersed in an electrolytic paste. This electrode/electrolytic build-up is then encased in a metal container, usually made of zinc, which itself acts as the anode(-) terminal. When the battery is in a discharge condi0tion an electrochemical reaction takes place resulting in one of the metals being consumed. Because of this consumption, the charging process is not reversible. Attempting to reverse the chemical reaction in a primary cell by way of recharging is usually dangerous and can lead to a battery explosion.

This batteries are commonly used to power items such as flash lights. The most common primary cells today are found in alkaline batteries, silver-oxide and lithium batteries. The earlier carbon-zinc cells, with a carbon post as cathode and a zinc shell as anode where once prevalent but are not as common.

SECONDARY CELL

A secondary cell is any kind of electrolytic cell in which the electrochemical reaction that releases energy is reversible. The lead-acid car battery is a secondary cell battery. The electrolyte is sulfuric acid (battery acid), the positive electrode is lead peroxide, and the negative electrode is lead. A typical lead-acid battery consists of six lead-acid cells in a case. Each cell produces 2 volts, so the whole battery produces a total of 12 volts.

Other commonly used secondary cell chemistry types are nickel cadmium(NiCd), nickel metal hydride (NiMH), lithium ion (Li-ion), and Lithium ion polymer(Li-ion polymer).

Lead-acid batteries used in aircraft are similar to automobile batteries. The lead-acid battery is made up of a series of identical cells each containing sets of positive and negative plates Figure 5-1 illustrates each cell contains positive plates of lead dioxide (Pbo2), negative plates of spongy lead, and electrolyte (sulphuric acid and water). A practical cell is constructed with many more plates than just two in order to get the required current output. All positive plates are connected together as well as the negatives. Because each positive plate is always positioned between two negative plates, there are always one or more negative plates than positive plates.

Between the plates are porous separators that keep the positive and negative plates from touching each other and shorting out the cell. The separators have vertical ribs on the side facing the positive plate. This construction permits the electrolyte to circulate freely around the plates. In addition, it provides a path for sediment to settle to the bottom of the cell.

Each cell is seated in a hard rubber casing through the top of which are terminal posts and a hole into which is screwed a non-spill vent cap. The hole provides access for testing the strength of the electrolyte and adding water. The vent plug permits gases to escape from the cell with a minimum of leakage of electrolyte, regardless of the position the airplane might assume. Figure 5-2 shows the construction of the vent plug. In level flight, the lead weight permits venting of gases through a small hole. In inverted flight, this hole is covered by the lead weight.

The individual cells of the battery are connected in series by means of cell straps. (Figure 5-3) The complete assembly is enclosed in an acid resisting metal container (battery box), which serves as electrical shielding and mechanical protection. The battery box has a removable top. It also has a vent tube nipple at each end. When the battery is installed in an airplane, a vent tube is attached to each nipple. One tube is the intake tube and is exposed to the slipstream. The other is the exhaust vent tube and is attached to the battery drain sump, which is a glass jar containing a felt pad moistened with a concentrated solution of sodium bicarbonate (baking soda). With this arrangement, the airstream is directed through the battery case where battery gases are picked up, neutralized in the sump, and then expelled overboard without damage to the airplane.

To facilitate installation and removal of the battery in some aircraft, a quick disconnect assembly is used to connect the power leads to the battery. This assembly attaches the battery leads in the aircraft to a receptacle mounted on the side of the battery. (Figure 5-4)

The receptacle covers the battery terminal posts and prevents accidental shorting during the installation and removal of the battery. The plug consists of a socket and a hand wheel with a course pitch thread. It can be readily connected to the receptacle by the hand wheel. Another advantage of this assembly is that the plug can be installed in only one position, eliminating the possibility of reversing the battery leads.

The voltage of lead acid cell is approximately 2 volts in order to attain the voltage required for the application. Each cell is then connected in series with heavy gage metal straps to form a battery. In a typical battery, such as that used in a aircraft for starting, the voltage required is 12 or 24 volts. This voltage is achieved by connecting six cells or twelve cells respectively together in series and enclosing them in one plastic box.

Each cell containing the plates are filled with an electrolyte composed of sulfuric acid and distilled water with a specific gravity of 1.270 at 600 F. This solution contains positive hydrogen ions and negative sulfate(SO4) ions that are free to combine with other ions and form a new chemical compound. When the cell is discharged, electrons leave the negative plate and flow to the positive plates where they cause the lead dioxide (PBO2) to break down into negative oxygen ions join with positive lead ions. The negative oxygen ions join with positive hydrogen ions from the sulfuric acid and form water (h2o). The negative sulfate ions join with the lead ions in both plates and form lead sulfate (PbSO4). After the discharge, the specific gravity changes to about 1.150

BATTERY RATINGS

The voltage of a battery is determined by the number of cells connected in series to form the battery. Although the voltage of one lead acid cell just removed from a charger is approximately 2.2 volts, a lead acid cell is normally rated at approximately 2 volts. A battery rated at 12 volts consists of 6 lead acid cells connected in series, and a battery rated at 24 volts is composed of 12 cells.

The most common battery rating is the amp-hour rating. This is a unit of measurement for battery capacity . It is determined by multiplying a current flow in amperes by the time in hours that the battery is being discharged.

A battery with a capacity of 1 amp-hour should be able to continuously supply a current of 1 amp to a load for exactly 1 hour, or 2 amps for ½ hour, or 1/3 amp for 3 hours, etc., before becoming completely discharged. Actually, the amp-hour output of a particular battery depends on the rate at which it is discharged. Heavy discharge current heats the battery and decreases its efficiency and total ampere hour output. For airplane batteries, a period of 5 hours has been established as the discharge time in rating battery capacity. However, this time of 5 hours is only a basis for rating and does not necessarily mean the length of time during which the battery is expected to furnish current. Under actual service conditions, the battery can be completely discharge within a few minutes, or it may never be discharge if the generator provides sufficient charge.

The amp-hour capacity of a battery depends upon its total effective capacity. Connecting batteries in series increases the total voltage but not the amp-hour capacity.

LIFE CYCLE OF A BATTERY

The accumulation of shed material, in turn, causes shorting of the plates and results in internal discharge. A battery that remains in a loe or discharge condition for a long period of time may be permanently damaged. The deterioration can continue to a point where cell capacity can dropto 80% after 1000 cycles. In a lot of cases the cell can continue working to nearly 2000 cycles but with a diminished capacity of 60% of its original state.

LEAD-ACID BATTERY TESTING METHODS

The state of charge of a storage battery depends upon the condition of its active materials, primarily the plates. However, the state of charge of a battery is indicated by the density of the electrolyte and is checked by a hydrometer, an instrument that measures the specific gravity (weight as compared with water) of liquids.

The most commonly used hydrometer consists of a small sealed glass tube weighted at its lower end so it will float upright. (Figure 5-5) Within the narrow stem of the tube is a paper scale with a range of 1.100 to 1.300. When a hydrometer is used, a quantity of electrolyte sufficient to float the hydrometer is drawn up into the syringe. The depth to which the hydrometer sinks into the electrolyte is determined by the density of the electrolyte, and the scale value indicated at the level of the electrolyte, the higher the hydrometer will float; therefore, the highest number on the scale (1.300) is at the lower end of the hydrometer scale.

In a new, fully charged aircraft storage battery, the electrolyte is approximately 30 percent acid and 70 percent water ( by volume) and is 1.300 times as heavy as pure water. During discharge, the solution (electrolyte) becomes less dense and its specific gravity drops below 1.300. A specific gravity reading between 1.300 and 1.275 indicates a high state of charge; between 1.275 and 1.240, a medium state of charge; and between 1.240 and 1.200, a low state of charge. Aircraft batteries are generally of small capacity but are subject to heavy loads. The values specified for state of charge are therefore rather high. Hydrometer tests are made periodically on all storage batteries installed in aircraft. An aircraft battery in a low state of charge may be perhaps 50 percent charge remaining, but is nevertheless considered low in the face of heavy demands that would soon exhaust it.

A battery in such a state of charge is considered in need of immediate recharging.

When a battery is tested using a hydrometer, the temperature of the electrolyte must be taken into consideration. The specific gravity readings on the hydrometer will vary from the actual specific gravity as the temperature changes. No correction is necessary when the temperature is between 700 F, it is necessary to apply a correction factor. Some hydrometers are equipped with a correction scale inside the tube. With other hydrometers, it is necessary to refer to a chart provided by the manufacturer. In both cases, the corrections should be added to, or subtracted from the reading shown on the hydrometer.

The specific gravity of a cell is reliable only if nothing has been added to the electrolyte except occasional small amounts of distilled water to replace that lost as a result of normal evaporation. Always take hydrometer readings before adding distilled water, never after. This is necessary to allow time for the water to mix thoroughly with electrolyte and to avoid drawing up into the hydrometer syringe a sample that does not represent the true strength of the solution .

Exercise extreme care when making the hydrometer test of a lead-acid cell. Handle the electrolyte carefully because sulfuric acid will burn clothing and skin, wash the area thoroughly with water and then apply bicarbonate of soda.

**LEAD- ACID BATTERY CHARGING METHODS**

Passing direct current through the battery in a direction opposite to that of the discharge current may charge a storage battery. Because of the internal resistance (IR) in the battery, the voltage of the external charging source must be greater than the open circuit voltage. For example, the open circuit voltage of a fully charged 12 cell , lead- acid battery is approximately 26.4 volts (12x 2.2 volts), but approximately 28 volts are required to charge it. This larger voltage is needed for charging because of the voltage drop in the battery caused by the internal resistance. Hence, the charging voltage of a lead acid battery must equal the open circuit voltage plus the IR drop within the battery (product of the charging current and the internalresistance).

The internal resistance of a battery increases over time. The active material inside the battery converts to lead sulfate builds up and as it does, resistance increases. The internal resistance can be calculated using the difference between the no load voltage and the load voltage for a particular circuit. This voltage drop is caused by the internal resistance can be calculated. Theoretical discussions and circuit diagram assume a battery has zero resistance. The technician in the field must be aware that this is not the case.

Batteries are charged by either the constant voltage or constant current method. In the constant voltage method (Figure 5-6A), a motor generator set with a constant, regulated voltage forces the current through the battery. In this method, the current at the start of the process is high but automatically tapers off, reaching a value of approximately 1 ampere when the battery is fully charged. The constant voltage method requires less time and supervision than does the constant current method (Figure 5-6B), the current remains almost constant during the entire charging process.

This method requires a longer time to charge a battery fully and, toward the end of the process, presents the danger of overcharging, if care is not exercised. In the aircraft, the storage battery is charged by direct current from the aircraft generator system. This method of charging is the constant voltage method, since the generator voltage is held constant by use of a voltage regulator.

When a storage battery is being charged, it generates a certain amount of hydrogen and oxygen. Since this is an explosive mixture, it is important to take steps to prevent ignition of the gas mixture. Loosen the vent caps and leave in place. Do not permit open flames, sparks, or other sources of ignition in the vicinity. Before disconnecting or connecting a battery to the charge, always turn off the power by means of a remote switch.

**NICKEL- CADMIUM BATTERIES**

**CHEMISTRY AND CONSTRUCTION**

Active materials in nickel-cadmium cells (Ni-Cad) are nickel hydrate (NiOOH) in the charged positive plate (Anode) and sponge cadmium (Cd) in the charged negative plate (Cathode). The electrolyte is a potassium hydroxide (KOH) solution in concentration of 20-34 percent by weight pure KOH in distilled water.

Sintered nickel-cadmium cells have relatively thin sintered nickel matrices forming a plate grid structure. The grid structure is highly porous and is impregnated with the active positive material (nickel- hydroxide) and the negative material (cadmium-hydroxide). The plates are then formed by sintering nickel powder to fine-mesh wire screen. In other variations of the

process the active material in the sintered matrix is converted chemically, or thermally, to an active state and then formed. In general, there are many steps to these cycles of impregnation and formation.

Thin sintered plate cells are ideally suited for very high rate charge and discharge service. Pocket plate nickel-cadmium cells have the positive or negative active material, pressed into pockets of perforated nickel plated steel plates or into tubes. The active material is trapped securely in contact with a metal current collector so active material shedding is largely eliminated. Plate designs vary in thickness depending upon cycling service requirements. The typical open circuit cell voltage of a nickel- cadmium battery is about 1.25 volts.

**OPERATION OF NICKEL-CADMIUM CELLS**

When a charging current is applied to a nickel-cadmium battery, the negative plates lose oxygen and begin forming metallic cadmium. The active material of the positive plates, nickel-hydroxide, becomes more highly oxidized. This process continues while the charging current is applied or until all the oxygen is removed from the negative plates and only cadmium remains.

Towards the end if the charging cycle, the cells emit gas. This will also occur if the cells are overcharged. This gas is caused by decomposition of the water in the electrolyte into hydrogen at the negative plates and oxygen at the positive plates. The voltage used during charging, as well as the temperature, determines when gassing will occur. To completely charge a nickel-cadmium battery, some water will be used.

The chemical action is reversed during discharge. The positive plates slowly give up oxygen, which is regained by the negative plates. This process results in the conversion of the chemical energy into electrical energy. During discharge, the plates absorb a quantity of the electrolyte. On recharge, the level of the electrolyte rises and, at full charge, the electrolyte will be at its highest level. Therefore, water should be added only when the battery is fully charged.

The nickel-cadmium battery is usually interchangeable with the lead-acid type. When replacing a lead acid battery with a nickel-cadmium battery, the battery compartment must be clean, dry, and free of all traces of acid from the old battery. The compartment must be washed out and neutralized with ammonia or boric acid solution, allowed to dry thoroughly and then painted with an alkali resisting varnish.

The pad in battery sump jar should be saturated with a three percent (by weight) solution of boric acid and water before connecting the battery vent system.

**GENERAL MAINTENANCE AND SAFETY PRECAUTIONS**

Refer to the battery manufacturer for detailed service instructions. Below are general recommendations for maintenance and safety precautions. For vent nickel cadmium cells, general maintenance requirements are:

1. Hydrate cells to supply water lost during overcharging.
2. Maintain inter-cell connectors at proper torque values.
3. Keep cell tops and exposed sides clean and dry.

Electrolyte spillage can form grounding paths. White moss around vent cap seals is potassium carbonate (K2CO3). Clean up these surfaces with distilled water and dry. While handling the caustic potassium hydroxide electrolyte, wear safety goggles to protect the eyes. The technician should also wear plastic gloves and an apron to protect skin and clothes, neutralize the alkali immediately with vinegar or dilute boric acid solution (one pound per gallon of water); then rinse with clear water.

During overcharging conditions, explosive mixtures of hydrogen and oxygen develop in nickel-cadmium cells. When this occurs, the cell relief valves vent these gases to the atmosphere, creating a potentially explosive hazard. Additionally, room ventilation should be such as to prevent a hydrogen build up in closed spaces from exceeding one percent by volume. Explosions can occur at concentrations above four percent by volume in air.

**SEALED LEAD ACID BATTERIES**

In many applications, sealed lead acid (SLA) batteries are gaining in use over the Ni-Cad batteries. One leading characteristics of Ni-Cad batteries is that they perform well in low voltage, full-discharge, high cycle applications. However, they do not perform as well in extended standby applications, such as auxiliary or as emergency battery packs used to power inertial reference units or stand-by equipment (attitude gyro).

It is typical during the servicing of a Ni-Cad battery to match as many as twenty individual cells in order to prevent unbalance and thus cell reversal duringend of discharge. When a Ni-Cad does reverse, very high pressure and heat can result. The result is often pressure seal rupture, and in the worst case, a cell matching is inherent in each battery. Ni-Cads also have an undesirable characteristics caused by constant overcharge and infrequent discharges, as in standby applications. It is technically known as “voltage depression” and commonly but erroneously called “memory effect”. This characteristic is only detectable when a full discharge is attempted. Thus, it is possible to believe a full charge exists, while in fact it does not. SLA batteries do not have this characteristics voltage depression (memory) phenomenon, and therefore do not require scheduled deep cycle maintenance as do Ni-Cads.

The Ni-Cad emergency battery pack requires relatively complicated test equipment due to the complex characteristics of the Ni-Cad. Sealed lead acid batteries do not have these temperamental characteristics and therefore it is not necessary to purchase special battery maintenance equipment. Some manufactures of SLA batteries have included in the battery can be tested while still installed on the aircraft. Ni-Cads must

have a scheduled energy test performed on the bench due to the inability to measure their energy level on the aircraft, and because of their notable “memory’ shortcoming.

The SLA battery can be designed to alert the technician if a battery is failing. Furthermore, it may be possible to test the failure detection circuits by activating a Built in Test (BITE)button. This practice significantly reduces regulatory paperwork and maintenance workload.

**THERMOCOUPLES**

Thermocouple means for generation of electricity, thermocouples have significantapplication in aviation and in high-temperature engine indicating systems.

A thermocouple is a circuit or connection of two unlike metals. The metals are touching at two separate junctions. One of the junctions is placed in an area where temperature needs to be monitored. The other junction is remotely located in a flight deck instrument or in an area where voltage can be forwarded to data computer. When the temperature rises at the “hot junction”, an electromotive force is produced in the circuit. This voltage is directly proportional to the temperature. By measuring the amount of electromotive force, temperature can be determined.

As stated, the thermocouples are used to measure high temperatures. Two common applications are the measurement of cylinder head temperature (CHT) in reciprocating engines and exhaust gas temperature (EGT) in turbine engines. Thermocouple junctions are made from a variety of metals, depending on the temperature range required to be measured and the maximum temperature to which they are exposed. Iron and constantan, or copper and constantan, are common materials for CHT measurement in millivolts. This limits the use of the electricity produced.

When thermocouples are used in fire detection systems, the temperature different between the two junctions of metals will remain negligible in normal conditions. When a fire or overheat condition exists at one of the junctions, electricity is produced and amplified to set off an alarm.

**PHOTO-CELLS**

Photo-cells are a source of electricity with applications in electronics and electronic control of mechanical systems. Light contains electromagnetic energy that is carried by photon. All semiconductors are affected by light energy. When a photon strikes a semiconductor atom, it raises the energy level above what is needed to hold its electrons in orbit. The extra energy frees an electron enabling it to flow as current. This current can be used in a circuit to initiate any number of actions such as energizing a coil to close a circuit enabling its operation.

* 1. **CIRCUITS DC**
* Ohms law, kirchoff’s voltage and current laws;
* Calculations using the above laws to find resistance, voltage and current;
* Significance of the internal resistance of a supply.

SERIES DC CIRCUITS

**INTRODUCTION**

The series circuit is the most basic electrical circuit and provides a good introduction to basic circuit analysis. The series circuit represents the first building block for all of the circuits to be studied and analyzed. Figure 6-1 shows this simple circuit with nothing more than a voltage source or battery, a conductor, and a resistor. This is classified as a series circuit because the component equally. There is only one path for the current to take and the battery and resistor are in series with each other. Next is to make a few additions to the simple circuit in figure 6-1.

Figure 6-2 shows an additional resistor and a little more detail regarding the values. With these values, we can now begin to learn more about the nature of the circuit. In this configuration, there is a 12volt DC source in series with two resistors, R1 = 10Ω and R2 =30 Ω. For resistors in a series configuration, the total resistance of the circuit is equal to the sum of the individual resistors. The basic formula is:

RT = R1+R2+R3+……..RN

For Figure 6-2, this will be:

RT=10 Ω +30 Ω

RT = 40 Ω

Now that the total resistance of the circuit is known, the current for the circuit can be determined. In a series circuit, the current cannot be different at different point within the circuit. The current through a series circuit will always be the same through each element and at any point. Therefore, the current in the simple circuit can now be determined using Ohm’s law:

Formula, E= I (R)

Solve for current, I = E/R

The variable, E = 12V and RT=40Ω

Solve for current, I = 12V/40 Ω

Current in circuits, I = 0.3 A

Ohm’s law describes a relationship between the variables of voltage, current, and resistance that is linear and easy to illustrate with a few extra calculations. First will be the act of changing the total resistance of the circuit while the other two remain constant. In this example, the RT of the circuit in Figure 6-2 will be doubled. The effects on the total current in the circuits are:

Formula, E= I (R)

Solve for current, I= E/R

The variable, E = 12 V and RT = 80Ω

Solve for current, I = 12V/80Ω

Current in circuits, I = 0.15 A

It can be seen quantitatively and intuitively that when the resistance of the circuit is doubled, the current is reduced by half the original value.

Next, reduce the RT of the circuit in Figure 6-2 to half of its original value. The effects on the total current are :

Formula , E = I(R)

Solve for current, I = E/R

The variables, E = 12V and RT = 20Ω

Solve for current, I = 12V/20Ω

Current in circuits, I = 0.6A

**VOLTAGE DROPS AND FURTHER APPLICATIONS OF OHM’S LAW**

The example circuit in Figure 6-3 will be used to illustrate the idea of voltage drop. It is important to differentiate between voltage and voltage drop when discussing series circuit. Voltage drop refers to the loss in electrical pressure or EMF caused by forcing electrons through a resistor. Because there are two resistors in the example, there will be separate voltage drop. Each drop is associated with each individual resistor. The amount of electrical pressure required to force a given number of electrons through a resistance is proportional to the size of the resistor.

In Figure 6-3, the values used to illustrate the idea of voltage drop are :

Current, I = 1 Ma

R1 = 1 kΩ

R2 = 3 k Ω

R3 = 5 k Ω

The voltage drop across each resistor will be calculated using ohm law.The drop for each resistance and the total current in the circuit. Keep in mind that the same current flows through series resistor.

Formula, E = I(R)

Voltage across R1:E1 = IT (R1)

E1= 1mA (1kΩ) = 1 volt

Voltage across R2:E2= IT (R2)

E2 = 1mA (3kΩ) = 3 volt

Voltage across R3: E3=IT (R3)

E3=1mA (5kΩ) = 5 volt

The source voltage can now be determined, which can then be used to confirm the calculations for each voltage drop.

Using ohm’s law:

Formula: E=I(R)

Source voltage= current times the total resistance

ES = I(RT)

RT = 1kΩ+3kΩ+5kΩ

RT= 9kΩ

Now: ES=I(RT)

Substitute ES = 1mA (9kΩ)

ES = 9 volts

Simple checks to confirm calculation and to illustrate the concept of voltage drop add up the individual values of the voltage drops and compare them to the results of the above calculation.

1volt + 3volt + 5volt = 9volts

**VOLTAGE SORCES IN SERIES**

A voltage source is an energy source that provides a constant voltage to a load. Two or more of these sources in series will equal the algebraic sum of all the sources connected in series. The significance of pointing out the algebraic sum is to indicate that the polarity of the sources must be considered when adding up the sources. The polarity will be indicated by a plus or minus sign depending on the sources position in the circuit.

In figure 6-4 all of the sources are in the same direction in terms of their polarity. All of the voltages have the same sign when added up. In the case of figure 6-4, three cells of the value of 1.5 volts are in series with the polarity in the same direction.

The addition in simple enough:

ET = 1.5 v + 1.5 v + 1.5 v = + 4.5 volts

However, in figure 6-5, one of the three sources has been turned around, and the polarity opposes the other two sources. Again the addition is simple:

ET = + 1.5v - 1.5v + 1.5v = + 1.5v

**KIRCHHOFF’S VOLTAGE LAW**

A law of basic importance to the analysis of an electrical circuit is kirchhoff’s voltage law. This law simply states that the algebraic sum of all voltages around a closed path or loop is zero. Another way of saying it: The sum of all the voltage drops equals the total source voltage. A simplified formula showing this law is shown below:

With three resistors in the circuit:

ES – E1 – E2 – E3……- EN = 0 volts

The source voltage equals the sum of the voltage drops. The polarity of the voltage drop is determined by the direction of the current flow. When going around the circuit, notice that the polarity of the resistor is opposite that of the source voltage. The position on the resistor is facing the position on the source and the negative towards the negative.

Figure 6-6 illustrates the very basic idea of kirchhoff’s voltage law. There are two resistors in this example. One has a drop of 14 volts and the other has a drop of 10volts. The source voltage must equal the sum of the voltage drops around the circuit. By inspection it is easy to determine the source voltage as 24 volts.

Figure 6-7 shows a series circuit with three voltage drops and 1one voltage source rated at 50volts.Two of the voltage drops are known. However, the third is not known. Using kirchhoff’s voltage law, the third voltage drop can be determined.

With three resistors in the circuit:

ES - E1 – E2 – E3= 0 volts

Substitute the known values:

24v-12v-10v-E3=0

Collect known values: 2v – E3 = 0

Solve for the unknown: E3 = 2volts

Determine the value of E4 in Figure 6-8. For this example, I = 200mA

First, the voltage drop across each of the individual resistors must be determined.

E1= I (R1)

E1 = (200mA)(10Ω)

Voltage drop across R1 E1 = 2 Volts

E2 = I (R2)

E2=(200mA)(50Ω)

Voltage drop across R2 E2 = 10 volts

E3 = I (R3)

E3 = (200mA)(100Ω)

Voltage drop across R3 E3 = 20 Volts

Kirchhoff’s voltage law is now employed to determine the voltage drop across E4

With four resistors in the circuit :

ES-E1-E2-E3-E4 = 0 Volts

Substituting values: 100v - 2v - 10v - 20v - E4 = 0

Combine: 68v –E4 = 0

Solve for unknown: E4 = 68 v

Using Ohm’s law and substituting in E4, the value for R4 can now be determined.

Ohm’s law: R = E/I

Specific application: R4 = E4/I

Substituting values : R4 = 68V/200mA

Values for R4 : R4 = 340Ω

**VOLTAGE DIVIDERS**

Voltage dividers are devices that make it possible to obtain more than one voltage from a single power source. A voltage divider usually consists of a resistor, or resistors connected in series, with fixed or movable contacts and two fixed terminal contacts. As current flows through the resistor, different voltages can be obtained between the contacts.

Series circuits are used for voltage dividers. The voltage divider rule allows the technician to calculate the voltage across one or a combination of series resistors without having to first calculate the current in the circuit.

Because the current flows through each resistor, the voltage drops are proportional to the ohmic values of the constituent resistors. A typical voltage divider is shown in Figure 6-9

To understand how a voltage divider works, examine Figure 6-10 carefully and observe the following.

Each load draws a given amount of current: I1, I2, I3. In addition to the load currents, some bleeder current (IB) flows. The current (IT) is drawn from the power source and is equal to the sum of all currents.

The voltage at each point is measured with respect to a common point. Note that the common point is the point at which the total current (IT) divides into separate currents ( I1, I2,I3).

Each part of the voltage divider has a different current flowing in it. The current distribution is as follows:

Through R1 \_ bleeder current (IB)

Through R2\_ IB plus I1

Through R3\_ IB plus I1, plus I2

The voltage across each resistor of the voltage divider is :

90 volts across R1

60 volts across R2

50 volts across R3

The voltage divider circuit discussed up to this point has had one side of the power supply (battery) at ground potential. In Figure 6-11 the common reference point (ground symbol) has been moved to a different point on the voltage divider. The voltage drop across R1 is 20 volts; however, since tap A is connected to a point in the circuit that is at the same potential as the negative side of the battery, the voltage between tap A is and the reference point is a negative (-) 20 volts. Since resistors R2 and R3 are connected to the

positive side of the battery, the voltages between the reference point and Tab B or tab C are positive.

The following rules provide a simple method of determining negative and positive voltages: (1) If current enters a resistance flowing away from the reference point, the voltage drop across the resistance is positive in respect to the reference point; (2) if current flows out of a resistance towards the reference point, the voltage drop across the resistance is negative in respect to the reference point. It is the location of the reference point that determines whether a voltage is negative or positive.

Tracing the current flow provides a means for determining the voltage polarity. Figure 6-12 shows the same circuit with the polarities of the voltage drops and the direction of the current flow indicated. The current flows from the negative side of the battery to R1. Tap A is at the same potential as the negative terminal of the battery since the slide voltage drop caused by the resistance of the conductor is disregarded; however, 20volts of the source voltage are required to force the current through R1 and this 20 volt drop has the polarity indicated. Stated another way, there are only 80 volts of electrical pressure left in the circuit on the ground side of R1.

When the current reaches Tap B, 30 more volts have been used to move the electrons through and in a similar manner the remaining 50 volts are used for R3. But the voltages across R2 and R3 are positive voltages, since they are above ground potentialR2.

Figure 6-13 shows the voltage divider used previously. The voltage drops across the resistances are the same;

However, the reference point (ground) has been changed. The voltage between ground and tap A is now a negative 100 volts, or the applied voltage. The voltage between ground and tap B is a negative 80volts, and the voltage between ground and tap C is a negative 50 volts.

**DETERMINING THE VOLTAGE DIVIDER FORMULA**

Figure 6-14 shows the example network of four resistors and a voltage source. With a few simple calculations, a formula for determining the voltage divisions in a series circuit can be determined. The voltage drop across any particular resistor shall be called EX, where the subscript x is the value of a particular resistor (1, 2, 3, or 4). Using Ohm’s law, the voltage drop across any resistor can be determined.

Ohm’s law: EX = I (Rx)

As seen earlier in the text, the current is equal to the source voltage divided by the total resistance of the series circuit.

Current: I = ES/RT

The current equation can be now be substituted into the equation for Ohm’s law:

Substitute: EX = (ES/RT)(RX)

Algebraic rearrange: EX = (RX/RT)(ES)

This equation is the general voltage divider formula. The explanation of this formula is that the voltage drop across any resistor or combination of resistors in a series circuit is equal to the ratio of the resistance value to the total resistance, divided by the value of the source voltage. Figure 6-15 illustrates this with a network of three resistors and one voltage source.

EX = (RX/RT) ES

RT = 100+300+600= 1000

ES = 100 volts

Voltage drop over 100 Ω resistor is:

EX = (100Ω/1000Ω)100 volts

E100Ω = 10 V

Voltage drop over 300Ω resistor is:

EX = (300Ω/1000Ω)100 V

E100Ω = 30 V

Voltage drop over 600 Ω resistor is:

EX = (600Ω/1000 Ω)100 V

E100Ω = 60 V

Checking work:

ET = 10V +30V + 60V = 100 V

**PARALLEL DC CIRCUITS**

OVERVIEW

A circuit in which two or more electrical resistances or loads are connected across the same voltage source is called the parallel circuit. The primary difference between the series circuit and parallel circuit is but more than 1 path is provided for the current in parallel circuit. Each of these parallel paths is called a branch. The minimum requirements for parallel circuits are the following :

* A power source
* Conductor
* A resistance or load for each current path
* Two or more paths for current flow

Figure 6-16 depicts the most basic parallel circuit. Current flowing out of the source divides at point A in the diagram and goes through R1 and R2. As more branches are added to the circuit, more paths for the source current are provided.

**VOLTAGE DROPS**

The first point to understand is that the voltage across any branch is equal to the voltage across all of the other branches.

**TOTAL PARALLEL RESISTANCE**

The voltage across any branch is equal to the voltage across all of the other branches.

The parallel circuit consists of two or more resistors connected in such a way as to allow current flow to pass through all of the resistors at once. This eliminates the need for current to pass one resistor before passing through the next. When resistors are connected in parallel, the total resistance of the circuit decreases. The total resistance of a parallel combination is always less than the value of the smallest resistor in the circuit. In the series circuit, the current has to pass through the resistor one at a time. This gave a resistance to the current equal the sum of all the resistors. In the parallel circuit, the current has several resistors that it can pass through, actually reducing the total resistance of the circuit in relation to any one resistor value.

The amount of current passing through each resistor will vary according to its individual resistance. The total current of the circuit is the sum of the current in all branches. It can be determined by inspection that the total current will be greater than that of any given branch. Using Ohm’s law to calculate the resistance based on the applied voltage and the total current, it can be determined that the total resistance is less than any individual branch.

An example of this is if there was a circuit with the 100Ω resistor and a 5Ω resistor; while the exact value must be calculated, it still can be said that the combine resistance between the two will be less than the 5Ω.

**RESISTORS IN PARALLEL**

The formula for the total parallel resistance is as follows:

1/RT= 1/R1+ 1/R2 + 1/R3 +……1/RN

If the reciprocal of both sides is taken, then the general formula for the total parallel resistance is:

RT = 1/1/R1+1/R2+1/R3+…….+1/RN

TWO RESISTORS IN PARALLEL

Typically, it is more convenient to consider only two resistors at a time because this set up occurs in common practices. Any number of resistors in a circuit can be broken down into pairs. Therefore, the most common method is to use the formula for two resistors in parallel.

RT = 1/R1 + 1/R2

Combining the terms in the denominator and rewriting:

RT = R1R2/R1+R2

Put in words, this states that the total resistance for two resistors in parallel is equal to the product of both resistors divided by the sum of the two resistors. In the formula below, calculate the total resistance.

General formula: RT = R1R2/R1 + R2

Known values: R1 = 500 Ω

R2 = 400 Ω

RT = 500Ω x 400Ω/500Ω + 400 Ω

RT = 200000 Ω/ 900 Ω

RT = 222.22 Ω

**CURRENT SOURCE**

A current source is an energy source that provides a constant values of current to a load even when the load changes in resistive value. The general rule to remember is that the total current produced by current sources in parallel is equals to the algebraic sum of the individual sources.

**KIRCHHOFF’S CURRENT LAW**

Kirchhoff’s current law can be stated as: The sum of the currents into a junction or node is equal to the sum of the current flowing out of that same junction or node. A junction can be defined as a point in the circuit where two or more circuit paths come together. In the case of the parallel circuits, it the point in the circuit where the individual branches join.

General formula: IT = I1 + I2+ I3

Refer to figure 6-17 for an illustration. Point A and point B represent to junctions or nodes in the circuit with resistive branches in between. The voltage source provides a total current IT into node A. At this point, the current must divide, flowing out of node A into each of the branches according to the resistive value of each branch. Kirchhoff’s current law states that the current going in must equal that going out. Following the current through the three branches and back into node B, the total current IT entering node B and leaving node B is the same as that which entered node A. The current then continues back to the voltage source

Figure 6-18 shows that the individual branch currents are:

I1 = 5mA

I2 = 12 mA

The total current flow into the node A equals the sum of the branch currents, which is:

IT= I1 +I2

Substitute IT = 5Ma + 12mA

IT = 17mA

The total current entering node B is also the same.

Figure 6-19 illustrates how to determine an unknown current in one branch. Note that the total current into a junction of the three branches is known. Two of the branch currents in branch two can be determined.

General formula IT = I1 + I2 +I3

Substitute 75mA = 30mA + I2 + 20mA

Solve I2 I2 = 75mA – 30mA – 20mA

I2 = 25Ma

**CURRENT DIVIDERS**

It can now be easily seen that the parallel circuit is a current divider. As could be seen in Figure 6-16, there is a current through each of the two resistors. Because the same voltage is applied across both resistors in parallel, the branch currents are inversely proportional to the ohmic values of resistors. Branches with higher resistance have less current than those with lower resistance. For example, if the resistor value of R2 is twice as high as that of R1, the current in R2 will be half of that of R1. All of this can be determined with ohm’s law.

By ohm’s law, the current through any one of the branches can be written as:

Ix = ES/RX

The voltage source appears across each of the parallel resistors and RX represents any one of the resistors. The source voltage is equal to the total current times the total parallel resistance.

ES ITRT

Substituting ITRT FOR ES IX ITRT/RX

Rearranging IX  (RT/RX) IT

I2 (R2/RT) IT And I1 (R1/RT) IT

This formula is the general current divider formula. The current through any branch equals the total parallel resistance divided by the individual branch resistance, multiplied by the total current.

**SERIES-PARALLEL DC CIRCUITS**

OVERVIEW

Most of the circuits that the technician will encounter will not be a simple series or parallel circuit. Circuits are usually a combination of both, known as series - parallel circuit, which are groups consisting of resistors in parallel and in series. An example of this type of circuit can be seen in Figure 6-20.With the series-parallel circuit can initially appear to be complex, the same rules that have been used for the series-parallel circuit can be applied to these circuits.

The voltage source will provide a current out to resistor R1, then to the group of resistors R2 and R3 and then to the next resistor R4 before returning to the voltage source.

The first step in the simplification process is to isolate the group R2 and R3 and recognize that they are a parallel network that can be reduced to an equivalent resistor.

Using the formula for parallel resistance:

R23 = R2R3/R2 + R3

R2 and R3 can be reduced to R23.Figure 6-21 now shows an equivalent circuit with three series connected resistors. The total resistance of the circuit can now be simply determined by adding up the values of resistors R1,R23, and R4.

DETERMINING THE TOTAL RESISTANCE

A more quantitative example for determining total resistance and the current in each branch in a combination circuits is shown in the following example. Also refer to Figure6-22

The first step to determine the current at junction A , leading into the parallel branch. To determine the IT, the total resistance RT of the entire circuit must be known. The total resistance of the circuit is given as

RT = R1 + R23

Where R23 = ( R2R3/R2 + R3 ) parallel network

Find REQ R23 = 2kΩ3kΩ/ 2kΩ + 3KΩ

Solve for REQ R23 = 6kΩ/5kΩ

R23 = 1.2KΩ

Solve for RT RT = 1KΩ + 1.2KΩ

RT = 2.2KΩ

With the total resistance RT now determined, the total IT can be determined. Using Ohm’s law:

IT = ES/RT

Substitute values IT = 24V/2.2KΩ

IT = 10.9 mA

Now using Kirchhoff’s law, the current in branch with R3 can be determined.

IT = I2 + I3

I3 = IT – I2

I3 = 10.9mA – 6.54mA

I3 = 4.36mA

* 1. **RESISTANCE/RESISTOR**

(a)

Resistance and affecting factors;

Specific resistance;

Resistor colour code, values and tolerances, preffered values, wattage ratings;

Resistors in series and parallel;

Calculattion of total resistance using series, parallel and series parallel combination;

Operation and use of potentiometers and rheostats;

Operation of wheat stone bridge.

(b)

Positive and negative temperature coefficient conductance ;

Fixed resistors, stability, tolerance and limitations, methods of constructions;

Variable resistors, thermistors, voltage dependent resistors;

Construction of potentiometers and rheostats;

Construction of wheatstone Bridge;

**OHM’S LAW (RESISTANCE)**

The two fundamental properties of current and voltage are related by a third property known as resistance. In any electrical circuit, when voltage is applied to it, a current will result. The resistance of the conductor will determine the amount of current that flows under the given voltage. In most cases, the greater the circuit resistance, the less the current. If the resistance is reduced, then the current will increase. This relation is linear in nature and is known as Ohm’s law.

By having a linearly proportional characteristic, it is meant that if one unit in the relationship increases or decreases by a certain percentage, the other variables in the relationship will increase or decrease by the same percentage. An example would be if the voltage across a resistor is doubled, then the current through the resistors doubles. It should be added that this relationship is true only if the resistance in the circuit remains constant. For it can be seen that if the resistance changes, current also changes. A graph of this relationship is shown in

Figure 7-1, which uses a constant resistance of 20Ω. The relationship between voltage and current in this example shows voltage plotted horizontally along the X axis in values from 0 to 120 volts, and the corresponding values of current are plotted vertically in values from 0 to 6.0 amperes along the Y axis.

A straight line drawn through all the points where the voltage and current lines meet represents the equation I = E/20 and is called a linear relationship.

If E = 10V

Then 10V/20Ω = 0.5A

If E = 60V

Then 60V/20Ω = 3A

If E = 120V

Then 120V/20Ω = 6A

Ohm’s law may be expressed as an equation, as follows:

Equation: 1

I = E/R

I = Current in amperes (A)

E = Voltage (V)

R = Resistance (Ω)

Where I is current in amperes, E is the potential difference measured in volts, and R is the resistance measured in ohms. If any two of these circuit quantities are known, the third may be found by simple algebraic transposition. With this equation, we can calculate current in the voltage and resistance are known. This same formula can be used to calculate voltage. By multiplying both sides of the equation 1 by R, we get an equivalent form of ohm’s law, which is:

Equation: 2

E =I(R)

Finally, if we divide equation 2 by I, we will solve for resistance:

Equation: 3

R = E/I

All three formulas presented in this section are equivalent to each other and are simply different ways of expressing ohm’s law. The various equations, which may be derived by transposing the basic law, v vcan be easily obtained by using the triangles in figure 7-2.

The triangles containing containing E, R, and I are divided into two parts, with E above the line and I x R below it. To determine an unknown circuit quantity with a thumb. The location of the remaining uncovered letters in the triangle will indicate the mathematical operation to be performed. For example, to find I, refer to figure 7-2A, and cover I with the thumb. The uncovered letters indicate that E is to be divided by R, or I=E/R. To find R, refer to figure 7-2B, and cover R with the thumb. The result indicates I is to be multiplied by R, or E= IxR.

This chart is useful when learning to use ohm’s law. It should be used to supplement the beginner’s knowledge of the algebraic method.

**RESISTANCE OF A CONDUCTOR**

While wire of any size or resistance value may be used, the word “conductor” usually refers to materials that offered low resistance to current flow, and the word “insulator” describes material that offer high resistance to current. There is no distinct dividing and between conductors and insulators under the proper conditions, all types of material conduct some current. Materials offering a resistance to current flow midway between the best conductors and the poorest conductors (insulators) their greatest application in the field of transistors.

The best conductors are materials, chiefly metals, which posses a large number of free electrons; conversely, insulators are mainly having few free electrons. The best conductors are silver, copper, aluminum and gold; but some non metals such as carbon and water, can be used as conductors. Materials such as rubber, glass, ceramics and plastics are such poor conductors that they are usually used as insulators. The current flow in some of these materials is so low that it is usually considered zero. The unit used to measure resistance is called ohm. The symbol for ohm is greek letter omega (Ω). The mathematical formulas, the capital letter R refers to resistance. The resistance of a conductor ans the voltage applied to it determine the number of amperes of current flowing through the conductor. Thus, one ohm of resistance will made the current flow through one ampere in a conductor to which a voltage of 1 volt is applied.

FACTORS AFFECTING RESISTANCE

The resistance of a metallic conductor is dependent on the type of conductor material. It has been pointed out that certain metals are commonly used as conductors because of large number of free electrons in their outer orbits. Copper is usually considered the best available conductor material, since a copper wire of a particular diameter offers a lower resistance to current flow than an aluminum wire of same diameter. However, aluminum is much lighter than the copper, and for this reason as well as cost considerations, aluminum is often used when the weight factor is important.

The resistance of a metallic conductor is and directly proportional to its length. The longer the length of a given size of wire, the greater the resistance. Figure 7-3 shows 2 wire conductors of different lengths. If 1 volt of electrical pressure is applied across two ends of thick and conductor that is 1 foot in length and the resistance to the moment of free electrons is assumed to be 1 ohm, the current flow is limited to 1 ampere. If the same size conductor is doubled in length, the same electrons set in motion by the 1 volt applied now find twice the resistance; consequently, the current flow will be reduced by one-half.

The resistance of a metallic conductor is inversely proportional tonthe cross- sectional area. This are may be triagular or even square, but is usually circular. If the cross-sectional area of a conductor is doubled, the resistance to curret flow wil be reduced in half. This is true because of the increased area in which an electron can move without collision or capture by an atom. Thus, the resistance varies inversely with the cross-sectional area of a conductor.

The fourth major factor influencing the resistance of a conductor is temperature. Although some substances, such as carbon, show a decrease in resistance as the ambient (surrounding) temperature increases, most materials used as conductors increase in resistance as temperature increases. The resistance of a few alloys, such as constantan and manganin, change very little as the temperature changes. The amount of increase in the resistance of a 1 ohm sample of a conductor, per degree rise in temperature above 0 degree celsius (C), the assumed standard, is called the temperature coefficient of resistance.

For each metal, this is a different value is approximately 0.004 27 ohm. Thus, a copper wire having a resistance of 50 ohms at a temperature of 0 degree Celsius will have an increase in resistance of 50 x 0.004 27, or 0.214 ohm, for each degree rise in temperature above 0 degree celsius. The temperature coefficient of resistance must be considered where there is an appreciable change in temperature of a conductor during operation. Charts listing the temperature coefficient of resistance for different materials are available. Figure 7-4 shows a table for “resistivity” of some common electric conductors.

Conductor material Resistivity

(ohm meters @ 20 c)

Silver 1.64\*10-8

Copper 1.72\*10-8

Aluminum 2.83\*10-8

Tungsten 5.83\*10-8

Nickel 7.80\*10-8

Iron 12.0\*10-8

Constantan 49.0\*10-8

Nichrome ll 110\*10

The resistance of a material is determined by four properties; material, length, area, and temperature. The first three properties are related by the following equation at T = 20° c.

R = (p\*L)/A

Where

R = resistance in ohms

P = resistivity of the material in circular mil-ohms per foot

L = length of the sample in feet

A = area in circular mils

**RESISTANCE AND ITS RELATION WIRESIZING**

**CIRCULAR CONDUCTORS**

(WIRES/CABLES)

Because it is known that the resistance of a conductor is directly proportional to its length, and if we are given the resistance of unit length of wire, we can readily calculate the resistance of any length of wire of that particular material having same diameter. Also, because it is known that the resistance of a conductor is inversely proportional to its cross-sectional area, we can calculate the resistance of a similar length of wire of the same material with any cross-sectional area. Therefore, if we know the resistance of a given conductor, we can calculate the resistance for any conductor of the same material at the same temperature.

Use the following formula which basically states that the relationship between cross-sectional area, length and resistance of a certain conductor will remain the same if the size or length of the conductor is changed:

R1/L1/A1=R2/L1/A1

If we have a conductor that is 1meter long with a cross-sectional area of 1mm2 and has a resistance of 0.017ohm, what is the resistance of 50m of wire from the same material but with a cross-sectional area of 0.25mm2?

R1/L1/A1 = R2/L1/A1

R2 = 0.017\* 50m/1m \* 1mm2/0.25mm2 = 3.4Ω.

System international (SI) units are commonly used in the analysis of electrical circuits. However, when referencing tables and charts for conductors sizes and ohmic values, be sure denominations are for the system in which you are working. Conductors in north america are still being manufactured using the foot as the unit length and the mil (one thousandth of an inch) as the unit of diameter. Therefore, the resistance of a conductor of a given AWG size is listed on the charts with the length of the feet and the diameter in mils. Any diameter or length in meters or cross-sectional area in square meters must be converted to an imperial denomination to reference the AWG chart. The conversion factors 1mil = 0.0254mm. and 1foot = .3048meter can be applied.

In the case of using copper conductors, we are spared the task of tedious calculators by using as shown in figure 7-5. Note that cross- sectional dimensions listed on the table are such that each decrease of one gauge number equals a 25 percent increase in the cross-sectional area. Because of this, a decrease of three gauge numbers represents an increase in cross-sectional area of approximately a 2:1 increase. Likewise, change of ten wire gauge numbers represent a 10:1 changre in cross-sectional area – also, by doubling the cross-sectional area of the conductor, the resistance is cut in half. A decrease of three wire gauge numbers cuts the resistance of the conductor of given length in half.

**REGULATORCONDUCTORS (BUS BARS)**

To compute the cross-sectional area of a conductor in square mils, the length in mils of one side is squared. In the case of rectangular conductor, the length of one side is multiplied by the length of the other. For example, a common rectangular conductor, the length of one side is multiplied by the length of the other. For example, a common rectangular bus bar (large, special conductor) in 3/8 inch thick and 4 inches wide. The 3/8-inch thickness may be expressed as 0.375 to mils (375mils\*4000mils = 1500000 square mils).

**TYPES OF RESISTORS**

**FIXED RESISTORS**

Figure7-6 is a schematic representation of a fixed resistor. Fixed resistors have built into the design a means of opposing current. The general use of a resistor in a circuit is to limit the amount of current flow. There are a number of methods used in construction and sizing of a resistor that control properties such as resistance value, the precision of the resistance value, and the ability to dissipate heat. While in some applications the purpose of the resistive element is used to generate heat, such as in propeller anti- ice boots, heat typically is the unwanted loss of energy.

**CARBON COMPOSITION**

The carbon composed resistor is constructed from a mixture of finely grouped carbon/graphite, an insulation material for filler, and a substance for binding the material together. The amount of graphite in relation to the insulation material to determine the ohmic or resistance value of the resistor. This mixture is compressed into a rod, which is then fitted with axial leads or ‘’ pigtails’’. The finished product is then sealed in an insulating coating for isolation and physical protection.

There are other types of fixed resistors in common use.

Included in this group are:

* Carbon film
* Metal oxide
* Metal film
* Metal glaze

The construction of a film resistor is acomplished by depositing a resistive material evenly on a ceramic rod. This resistive material can be graphite for the carbon film resistor, nickel chromium for the metal film resistor, metal and glass for the metal glaze resistor and last, metal and an insulating oxide for the metal oxide resistor.

**RESISTOR RATING**

It is very difficult to manufacture a resistor to an exact standard of ohmic values. Fortunately, most circuit requirements are not extremely critical. For many uses, the actual resistance in ohms can be 20 percent higher or lower than the value marked on the resistor without causing difficulty. The percentage variation between the marked value and the actual value of a resistor is known as the “ tolerance”of a resistor. Resistor coded for a 5 percent tolerance will not be more than 5 percent higher or lower than the value indicated by a color code. The resistor color code is made up of a group of colors, numbers, and tolerance values. Each color is represented by a number, and in most cases, by a tolerance value. (Figure 7-7)

When the color code is used with end- to – center band marking system, the resistor is normally marked with bands of color with one end of the resistor. The body or base color of the resistor has nothing to do with the color code, and in no way indicates a resistance value. To prevent confusion, this body will never be the same color as any of the bands indicating resistance value.

When the end – to – center band marking system is used, either 3 or 4 bands will mark the resistor.

1. The first color band (nearest the end of the resistor ) will indicate the first digit in the numerical resistance value. This band will never be gold or silver in color.
2. The second color band will always indicate the second digit of ohmic value. It will never be gold or silver in color.( Figure 7-8 )
3. The third color band indicates the number of zeros to be added to the two digits derived from the first and second bands, except in the following two cases: (A) If the third band is gold in color, the first two digits must be multiplied by 10 percent. (B) If the third band is silver in color, the first two digits must be multiplied by 1 percent.
4. If there is a fourth color band, it is used as a multiplier for percentage of tolerance, as indicated in the color code chart in Figure 7-7. If there is no fourth band, the tolerance is understood to be 20 percent.

Figure 7-8 provides an example, which illustrates the rules for reading the resistance value of a resistor marked with the end – to – center band system. This resistor is marked with three bands of color, which must be read from the end towards the center.

There is no fourth color band; therefore, the tolerance is understood to be 20 percent. 20 percent of 250000 Ω equals 50,000Ω.

Since the 20 percent tolerance is plus or minus:

Maximum resistance

= 250 000Ω + 50 000Ω

= 300 000Ω

Minimum resistance

= 250 000Ω – 50 000Ω

= 200 000Ω

The following paragraph provide a few extra examples of resistor color band decoding. Figure 7-9 contains a resistor with another set of colors.

This resistor code should be read as follows:

The resistance of the resistor is 86 000 + 10 percent ohms. The maximum resistance is 94 600 ohms, and the minimum resistance is 77 400 ohms.

As another example, the resistance of a resistor in Figure 7-10 is 960 + 5 percent ohms. The maximum resistance is 1008 ohms, and the minimum resistance is 912ohms.

Sometimes circuit considerations dictate the tolerance must be smaller than 20 percent. Figure 7-11 shows an example of a resistor with a 2 percent tolerance. The resistance value of this resistor is 2500 + 2 percent ohms. The maximum resistance is 2550 ohms, and the minimum resistance is 2450 ohms.

Figure 7-12 contains an example of a resistor with a black third color band. The color code value of black is zero, and the third band indicates the number of zeros to be added to the first two digits.

In this case, a zero number of zeros must be added to the first two digits; therefore, no zeros are added. Thus, the resistance value is 10 + 1 percent ohms. The maximum is 10.1 ohms, and the minimum resistance is 9.9 ohms. There are two exceptions to the rule stating the third color band indicates the number of zeros. The first of these exceptions is illustrated in figure 7-13. When the third band is gold in color, it indicates that the first two digits must be multiplied by 10 percent. The value of this resistor in this case is:

10 x 0.10 + 2% = 1= 0.02 ohms

When the third band is silver, as in the case in figure 7-14, the first two digits must be multiplied by 1 percent. The value of the resistor is

0.45 + 10 percent ohms.

Wire wound

Wire wound resistor typically control large amounts of current and have high power ratings. Resistors of this type are constructed by winding a resistance wire around an insulating rod, usually made of porcelain. The windings are then coated with an insulation material for physical protection and heat conduction. Both ends of the windings are then connected to terminals, which are used to connect the resistor to a circuit (figure 7-15)

A wire wound resistor with tap is a special type of fixed resistor that can be adjusted. The adjustments can be made by moving a slide bar tap or by moving the tap to a present incremental position. While the tap may be adjustable, the adjustments are usually set at the time of installation to a specific value and then operated in service as a fixed resistor. Another type of wire-wound resistor is that constructed of manganin wire, used where high precision is needed.

**VARIABLE RESISTORS**

Variable resistors are constructed so that the resistive value can be changed eaisly. This adjustment can be made manual or automatic, and the adjustments can be made while the system that it is connected to is in operation. There are two basic types of manual adjustor’s. One is the rheostat and the second is the potentiometer.

**RHEOSTAT**

The schematic symbol for the rheostat is shown in Figure 7-16. A rheostat is a variable resistor used to vary the amount of current flowing in a circuit. Figure 7-17 shows a rheostat connected in series with an ordinary resistance in a series circuit. As the slider arm moves from point A to B, the amount of rheostat resistance (AB) is increased. Since the rheostat resistance and the fixed resistance are in series, the total resistance in the circuit also increases, and the current in the circuit decreases. On the other hand, if the slider arm is moved toward point A, the total resistance decreases and the current in the circuit increases.

**POTENTIOMETER**

The schematic symbol for the potentiometer is shown in Figure 7-18. The potentiometer is considered a three terminal device. As illustrated, terminals 1 and 2 have the entire value of the potentiometer resistance between them. Terminal 3 is the wiper or moving contact. Through this wiper, the resistance between terminals 1 and 3 or terminals 2 and 3 can be varied. While the rheostat is used to vary the current in a circuit, the potentiometer is used to vary the voltage in a circuit. A typical use for this component can be found in the volume controls on an audio panel and input devices for flight data recorders, among many other applications.

In Figure 7-19A, a potentiometer is used to obtain a variable voltage from a fixed voltage source to apply to an electrical load. The voltage applied to the load is the voltage between points 2 and 3. When the slider arm is moved to point 1, the entire voltage is applied to the electrical device(load); when the arm is moved to point 3, the voltage applied to the load is zero. The potentiometer makes possible the application of any voltage between zero and full voltage to the load.

The current flowing through the circuit of Figure 7-19 leaves the negative terminal electron flow of the battery and divides, one part flowing through the lower portion of the potentiometer (points 3 to 2 ) and the other part through the load. Both parts combine at point 2 and flow through the upper portion of the potentiometer (points 2 to 1) back to the positive terminal of the battery. In view B of Figure7-19, a potentiometer and its schematic are shown.

In choosing a potentiometer resistance, the amount of current drawn by the load should be considered as well as the current flow through the potentiometer at all settings of the slider arm. The energy of the current through the potentiometer is dissipated in the form of heat. It is important to keep this wasted current as small as possible by making the resistance of the potentiometer as large as practicable. In most cases, the resistance of the potentiometer can be several times the resistance of the load. Figure 7-20 shows how a potentiometer can be wired to function as a rheostat.

**LINEAR POTENTIOMETERS**

In a linear potentiometer, the resistance between both terminal and the wiper varies linearly with the position of the wiper. To illustrate, one quarter of a turn on the potentiometer will result in one quarter of the total resistance. The same relationship exists when one-half or three-quarters of potentiometer movement. Figure 7-21 schematically depicts this.

**TAPERES POTENTIOMETERS**

Resistance varies in a nonlinear manner in the case of the tapered potentiometer. Figure 7-22 illustrates this. Keep in mind that one-half of full potentiometer travel doesn’t necessarily correspond to one-half the total resistance of the potentiometer.

**THERMISTORS**

Figure 7-23 shows the schematic symbol for the thermistor. The thermistor is a type of a variable resistor, which is temperature sensitive. This component has what is known as a negative temperature coefficient, which means that as the sensed temperature increases, the resistance of the thermistor decreases.

**PHOTOCONDUCTIVE CELLS**

The photoconductive cell is similar to the thermistor. Like the thermistor, it has a negative temperature coefficient. Unlike the thermistor, the resistance is controlled by light intensity this kind of component can be found in radio control heads where the intensity of the ambient light is sensed through the photoconductive cell resulting in the back lightening of the control heads to adjust to the cockpit lighting conditions. Figure 7-24 shows the schematic symbol component.

WHEATSTONE BRIDGE

A Wheatstone Bridge is a useful electric wiring circuit constructed of three resistors with known values (R1, R2, R3) and a voltmeter (VG). A fourth resistor (RX) of unknown value is also included as shown in Figure 7-25. When wired as shown, the voltage values at D and B vary with the total resistance on each side of the “bridge”. Stated another way, the ratio of R2/ R1 =RX / R3. Thus, when the resistance on both sides of the circuit bridge are equal, there is no difference in potential at points D and B and the voltmeter wired between these points indicates “0”.

To find the unknown value of RX, The equation above can be rewritten and solved for RX as follows: RX = R1 / R2\*R3. Alternatively, the voltage shown on the voltmeter can be used to calculate the unknown value of RX by using Kirchoff’s laws.

Of primary importance is the fact that when constructed as shown, the bridge circuit is balanced between both sides when the voltmeter indicates zero. It must be noted that similar bridge circuits can be used to measure capacitance, inductance and impedance.

* 1. **– POWER**

POWER AND ENERGY

POWER IN AN ELECTRICAL CIRCUIT

This section covers power in the DC circuit and energy consumption. Whether referring to mechanical or electrical systems, power is defined as the rate of energy consumption or conversion within that system- that is, the amount of energy used or converted in a given amount of time.

From the scientific discipline of physics, the fundamental expression for power is:

P= E/t

Where:

P =Power measured in Watts (W)

E = Energy measured in Joules (J)

t = Time measured in seconds (s)

The unit measurement for power is the watt (W), which refers to a rate of energy conversion of 1joule/second. Therefore, the number of joules consumed in 1 second is equal to the number of watts. A simple example is given below.

Suppose 300J of energy is consumed in 10 seconds.

What would be the power in watts?

General formula: P = energy/time

P = 300J/10s

P = 30W

The watt is named for James Watt, the inventor of the steam engine. Watt devised an experiment to measure the power of a horse in order to find a means of measuring the mechanical power of his steam engine. One horsepower is required to move 33 000 pounds 1 foot in 1 minute. Since power is the rate of doing work, it is equivalent to the work divided by time. Stated as a formula, this is:

Power = 33000ft-ib\60 sec

Electrical power can be rated in a similar manner. For example, an electric motor rated as a 1 horsepower motor requires 746watts of electrical energy.

POWER FORMULAS USED IN THE STUDY OF ELRCTRICITY

When current flows through, a resistive circuit, energy is dissipated in the form of heat. Recall that voltage can be expressed in the terms of energy and charge as given in the expression:

E=W/Q

Where:

E = potential difference in volts

W = energy expanded or absorbed in joules (J)

Q = Charged measured in coulombs

Current I, can also be expressed in terms of charged and time as given by the expression:

Current = Charged/ Time

Or,

I = Q/t

Where:

I = Current in Amperes(A)

Q = Charged in coulombs (c)

t = time

When voltage W/Q and current Q/t are multiplied, the charge Q is divided out leaving the basic expression from physics:

E x I = E/Q x Q/t x E/t = power

For a simple DC electrical system, power dissipation can then be given by the equation:

General power formula

Where P = I (E)

P = Power

I = current

E = Volts

If a circuit has a known voltage of 24 volts and a current of 2amps, then the power in the circuit will be :

P = I (E)

P = 2A (24V)

P = 48W

Now recall Ohm’s laws which states that E = I (R). If we now substitute IR for E in the general formula, we get a formula that uses only current I and resistance R to determine the power in a circuit.

P = I (IR)

Second form of power equation

P = I2R

If a circuit has a known current of 2 amps and a resistance of 100Ω, then the power in the circuit will be :

P = I2R

P = (2A)2 100Ω

P = 400W

Using Ohm’s law again, which can be stated as I = E/R, we can again make a substitution such that power can be determined by knowing only the voltage (E) and resistance (R) of the circuit.

I = (E/R)(E)

Third form of power equation

P = E2/R

If a circuit has a known voltage of 24 volts and a resistance of 20Ω, then the power in the circuit will be:

P = E2/R

P = (24V)2/20Ω

P = 28.8 W

**POWER IN A SERIESAND PARALLELCIRCUIT**

The total power dissipated in both a series and parallel circuit is equal to the sum of the power dissipated in each resistor in the circuit. Power is simply additive and can be stated as :

PT = P1 + P2 + P3+……..PN

Figure 8-1 provides a summary of all the possible transpositions of the Ohm’s law formula and the power formula.

**ENERGY IN AN ELECTRICAL CIRCUIT**

Energy is defined as the ability to do work. Because power is the rate of energy usage, power used over a span of time is actually energy consumption. If power and time are multiplied together, we will get energy.

The joule is defined as a unit of energy.There is another unit of measure which is perhaps more familiar. Because power is expressed in watts and time in seconds, a unit of energy can be called a watt second (Ws) or more recognizable from the electric bill, a kilowatt hour(kWh).

**3.9 – CAPACITANCE/CAPACITOR**

**CAPACITANCE**

Another important property in AC circuits besides resistance and inductance is capacitance. While inductance is represented in a circuit by a coil, capacitance is represented by a capacitor. Its most basic form the capacitor is constructed of two parallel plates separated by a nonconductor, called a dielectric. In an electrical circuit, a capacitor serves as a reservoir or storehouse for electricity.

CAPACITORS IN DIRECT CURRENT

When a capacitor is connected across a source of direct current, such as a storage battery in the circuit shown in Figure 9-1A, and the switch is then closed, the plate marked B becomes positively charged, and the A plate negatively charged. Current flows in the external circuit during the time the electrons are moving from B to A. The current flow in the circuit is at a maximum the instant the switch is closed, but continually decreases thereafter until it reaches zero. The current becomes zero as soon as the difference in voltage of A and B becomes the same as the voltage of the battery. If the switch is opened as shown in Figure 9-1B, the plates remain charged. Once the capacitor is shorted, it will discharge quickly as shown Figure9-1C.

It should be clear that during the time the capacitor is being charged or discharged, there is current in the circuit, even though the circuit is broken by the gap between the capacitor plates. Current is present only during the time of charged and discharged, and this period of time is usually short.

**THE RC TIME CONSTANT**

The time required for a capacitor to attain a full charge is proportional to the capacitance and the resistance of the circuit. The resistance of the circuit introduces the element of time into the charging and discharging of a capacitor.

When a capacitor charges or discharges through a resistance, a certain amount of time is required for a full charge or discharge. The voltage across the capacitor will not change instantaneously. The rate of charging or discharging is determined by the time constant of the circuit. The time constant of a series RC (resistor/capacitor) circuit is a time interval that equals the product of the resistance in ohms and the capacitance in farad and is symbolized by the greek letter tau(T)

T = RC