Amateur Wireless Station Operators License Exam

Study material 2017

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CHAPTER 1

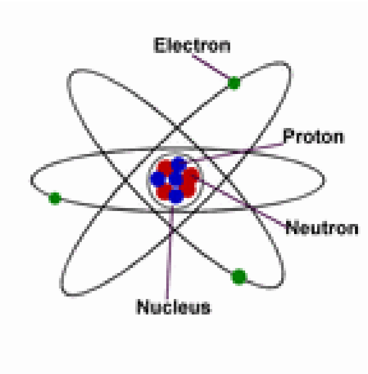
Chapter-1

ELEMENTARY ELECTRICITY AND MAGNETISM

Electricity

To explain Electricity we need to look deeply inside of everyday objects to consider their primary ingredients. They are

Atoms



As you probably know, everything in the world, whether solid, liquid, or gas, is made up of atoms. Each atom contains some number of electrons, protons, neutrons, and other sub-atomic stuff. The nucleus (central region) of each atom contains the protons (positive charge) and neutrons (no charge). Electrons (negative charge) live in a cloud around the outside. Since electrons and protons are charged particles, each atom prefers to have the same number of electrons as protons.

Molecules

Atoms of one or more types are organized into molecules. There are only a hundred or so types of atoms, but there are an almost infinite number of different molecules. Molecules are the building blocks from which all real objects are made.

Electricity

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

The Difference Between Electricity and Electronics

Obviously the words "electron", "electricity", and "electronics" are closely related. For historical reasons, we divide the science and engineering of electrons into two parts; electricity, and electronics. Electricity is the domain of motors, light bulbs, generators, and other "large scale" items. Electronics has come to mean the domain of vacuum tubes, transistors, integrated circuits, and other "small scale" items. We're covering electricity theory and practice here, because it is an important sub-set of electronics that can be dealt with as a stand-alone topic.

TYPES OF ELECTRICITY

Direct Current (DC)

The current, which flows in one direction in a circuit. DC voltage has a fixed polarity (e.g. a battery or an electrical cell) and the magnitude of the current remains constant. In an electrical circuit, the flow of electric current is indicated by an arrow mark originating from the positive terminal of the battery towards the negative terminal of the battery. This is the conventional method of showing the direction of current flow. But the real direction of electron flow is from the negative terminal of the battery to the positive terminal.

Alternating Current (AC)

Alternating current flows first in one direction then in the opposite direcion. The same definitions apply to alternatingvoltage. AC voltage switches polarity back and forth. AC voltage/current has a wave-form which represent the frequency of the source. The wave-form of the household ac is known as the 'sine' wave. The magnitude of the A.C. voltage changes with time. AC is obtained from A.C. generators.

Advantage of A.C. Heat is developed in all type of electrical circuits due to the flow of electric current. The magnitude of the D.C. being constant produces more heat in a circuit compared to the heat produced by an A.C. In long distance transmission lines, large amount of power will be dissipated in the form of heat if D.C. is used which can be reduced by the use of A.C.

Electricity - Conductors and Insulators

When you study high-school chemistry, you'll learn that some types of molecules feel more strongly about their electrons than do other types of molecules. This is a very useful characteristic for electricity and electronics.

Conductors

Some materials are willing to let a few electrons move from molecule to molecule. Materials that let electrons move through them are called "conductors".

Although some are better than others, most metals are good conductors of electricity. Silver, Gold, and Platinum are good conductors but are expensive, so they are only used when price is not important compared to function. Copper and Aluminum are also good conductors and are fairly inexpensive. Thus the wiring in our houses is copper, and the high voltage electric lines that we see crossing the country use aluminum cables.

Insulators

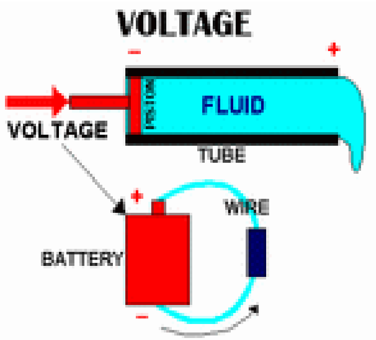
Other substances keep their electrons under very tight control. Materials that do not let electrons move through them are called "insulators".
Glass is an example of a type of material that keeps its electrons tightly controlled. Glass is made of silicon molecules, organized very tightly in to crystaline structures. Glass is an extremely good insulator. Many plastics are good insulators too. Plastics are cheap, flexible, and durable. That is why the wiring in our houses is covered with a layer of plastic.

What is charge?

Charge is an amount of electrons. Its unit is coulomb (C) and symbol is ‘q’. One coulomb is equivalent to 6 x 10^{18} electrons.

Voltage

Everyone uses this term, even though they might not understand it. You probably know that a single cell from a flashlight creates an electrical force of 1.5 Volts. You also know that a transistor radio battery (with the snaps on the top) creates an electrical force of 9 Volts. (There are six little cells of 1.5 Volts each inside of the 9 Volt battery.) You know that household electrical outlets are 220 or 240 Volts, and you know that "High Voltage" is dangerous.



What else should you know about voltage? Again, lets look at the atomic level.

Every atom has its own complement of electrons. In a conductor, some of those electrons can jump from atom to atom. But electrons don't move from atom to atom without a reason. When electrons are flowing there is always an electrical force pushing them along. We refer to this force as "Voltage".

Its unit is volt (V). One volt is defined as the **potential difference** that requires one joule of energy to move one coulomb of charge. Voltage is always measured relative to some other point in a circuit, e.g. the potential across a resistor

Current

In very simple terms, current is the flow rate of the electrons in the circuit. How is that different from voltage? Let's use a water tank and a pipe as an example.

In some neighborhoods you'll see a water tank raised high above the ground on strong legs. The water in this tank has been raised up there to create pressure in the system. A series of pipes carry the water down from the tank, under ground, into your house, and then to each sink, bathtub, and toilet. The water in your pipes is under pressure because the water in the tank is pushing down on it. This pressure is similar to Voltage. Voltage is the pressure pushing on the electrons in a circuit.

If all of the taps in your house are closed, no water flows through the pipes. If you open one tap, some water flows. If you open all of the tap, a lot of water flows. This flow of water is similar to electrical Current. Current is the flow rate of electrons through the circuit.

Current is the rate of flow of charge, i.e., the number of coulombs flowing past a point per second. Its unit is ampere (A) or amp. One ampere is equal to one coulomb per second.

Current and Power and Energy

The unit used to measure the flow of electricity, or current, is the ampere (A). The unit to measure power is the watt (W). Energy is measured in Joules (J).

Amperes are really a measure of a rate of electron flow (electrons per second), or equivalently, how much charge is passed per second (Coulombs per second). 1 A = 1 Coulomb per second, and 1 electron has a charge of $1.602 * 10^{-19}$ Coulombs.

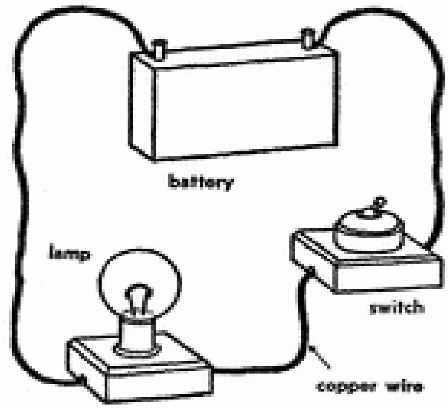
Power is measure in watts. A watt is an amount of energy per second, or Joules per second (1 W = 1 J/s).

The number of watts is for an electrical circuit given by the number of amperes times the voltage 1 W = 1 V * 1 A.

Energy is measured in Joules (in SI units), but power companies use units of kilowatt hours (kW hr). Since a watt is just a joule per second (J/s), a kilowatt hour is a measure of energy. Here is how you convert:

$1 \text{ kW hr} = 1000 \text{ W hr} = 1000 \text{ J/s hr} = 1000 \text{ J/s} * 3600 \text{ s} = 3.6 * 10^6 \text{ J}$

Are Voltage and Current Related?



Voltage and current are not the same thing, although they are closely related. In simple terms, Voltage causes Current. Given a Voltage and a path for the electrons, current will flow. Given the path, but no Voltage, or Voltage without the path, there will be no current.

This picture illustrates a single cell bed lamp. The battery is pushing the electrons through the bulb and the wire. Without this push, the electrons would be happy to remain stationary. In this case, chemical action within the battery causes the push. When the battery gets old, its chemical reaction slows down and its internal push gets weaker and weaker. (That's why the bulb gets dim.)

Who Does the Work?

Current, not Voltage, does the work in electrical circuits. The flow of water through a turbine is what makes the turbine spin. The flow of current through an electrical circuit is what lights the bulb, heats the stove, runs the motor, etc. Routing and controlling the flow of current is the goal of every electrical circuit.

What is a circuit? What are the parts of a circuit?

An electronic circuit is a complete course of conductors through which current can travel. Circuits provide a path for current to flow. To be a circuit, this path must start and end at the same point. In other words, a circuit must form a loop. An electronic circuit and an electrical circuit has the same definition, but electronic circuits tend to be low voltage circuits.

For example, in the above picture it includes four components: a battery , a lamp, a switch and the wire interconnect them. The circuit allows current to flow from the battery through the switch to the lamp, then back to the battery. Thus, the circuit forms a complete loop.

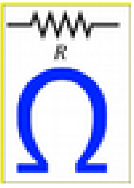
There are four parts to a circuit:

(1) There is a **source** of electricity Example: A battery
(2) There is a **path** along which charges can move. Example: A wire
(3) There is a **switch** that opens and closes the circuit. Example: A switch
(4) There is some **load** that **uses the electricity.** Example: A light bulb

Difference between a complete circuit and an incomplete circuit.

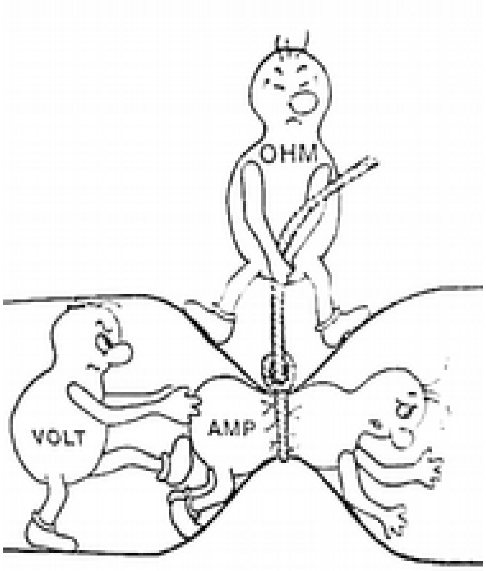
When a switch is closed or turned on, the path of electricity is complete. The charges move. A circuit whose path is complete is called a complete circuit. When the switch is open, or turned off, the path is broken. The movement of charges stops. The path is incomplete. A circuit whose path is incomplete is called an incomplete circuit.

Resistance



Resistance is the friction in an electrical circuit that controls the flow of current. As previously mentioned, voltage causes current. When a voltage is present and there is a path (circuit) for electron flow, then there will be a current. The ohm (symbol: Ω) is the unit of electrical resistance

Question: How much current will flow in a circuit ?



Answer: As much as can be produced by the pressure (Voltage) working against the friction (Resistance) of the circuit.

Closing a valve in your house water system will reduce the flow,like wise in electricity a resistor will reduce the flow of current. In electrical terms, the valve is an adjustable resistor.

Wires, like water pipes, have very low resistance. Other circuit elements are intentionally designed to have specific amounts of resistance in order to accomplish the operating goals of the circuit. Light bulb filaments, stove heating coils, and motor windings all have resistance that regulates the flow of current through them.

Why do we need Resistance?

Every real-world circuit must include an appropriate resistance so that there is an appropriate current flow. Recall the battery and bulb circuit on the voltage/current page. In that circuit the bulb is the primary circuit resistance. Here are three examples of voltage, resistance, and resulting current in that circuit:

1. Not Enough Resistance

If we use a 6 Volt battery and a bulb that is intended for 1.5 Volts, the pressure is too high and the filament resistance allows too much current to flow. We get a single bright flash as the bulb burns out!

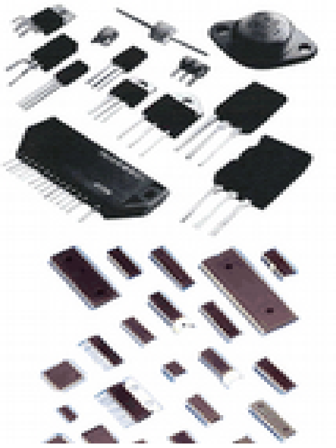
2. Too Much Resistance

If we use a 1.5 Volt battery and a bulb that is intended for 6 Volts, the pressure is too low and the filament resistance allows very little current to flow. The battery lasts for a very long time but the bulb is too dim to be of much use.

3. Exactly Enough Resistance

When we use a 1.5 Volt battery and a bulb that is also intended for 1.5 Volts, the current is just right. The bulb is bright, but not doesn't burn out, and the battery lasts for quite a while.

ACTIVE AND PASSIVE DEVICES

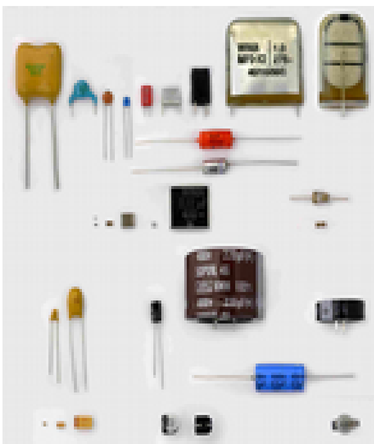


What are Active Devices?

An active device is any type of circuit component with the ability to electrically control electron flow . In order for a circuit to be properly called electronic, it must contain at least one active device. Examples of Active devices are vacuum tubes, transistors, silicon-controlled rectifiers (SCRs), and TRIACs etc.

All active devices control the flow of electrons through them.

What are Passive Devices?



Components incapable of controlling current by means of another electrical signal are called passive devices. Resistors, capacitors, inductors, transformers, and even diodes are all considered passive devices.

Passive devices are the resistors, capacitors, and inductors required to build electronic hardware. They always have a gain less than one, thus they can not oscillate or amplify a signal. A combination of passive components can multiply a signal by values less than one, they can shift the phase of a signal, they can reject a signal because it is not made up of the correct frequencies, they can control complex circuits, but they can not multiply by more than one because they lack gain.

Diodes

Diodes are basically a one-way valve for electrical current. They let it flow in one direction (from positive to negative) and not in the other direction. Most diodes are similar in appearance to a resistor and will have a painted line on one end showing the direction or flow (white side is negative). If the negative side is on the negative end of the circuit, current will flow. If the negative is on the positive side of the circuit no current will flow. More on diodes in later sections.

Integrated Circuits

Integrated Circuits, or ICs, are complex circuits inside one simple package. Silicon and metals are used to simulate resistors, capacitors, transistors, etc. It is a space saving miracle. These components come in a wide variety of packages and sizes. You can tell them by their "monolithic shape" that has a ton of "pins" coming out of them. Their applications are as varied as their packages. It can be a simple timer, to a complex logic circuit, or even a microcontroller (microprocessor with a few added functions) with erasable memory built inside.

Transistors

A transistor is a semiconductor device, commonly used as an amplifier or an electrically controlled switch. The transistor is the fundamental building block of the circuitry in computers, cellular phones, and all other modern electronic devices.

Transistors amplify when built into a proper circuit. A weak signal can be boosted tremendously.

Transistors use the properties of semi-conductors, seemingly innocuous materials like geranium and now mostly silicon.

Capacitors

A capacitor is a passive electrical component that can store energy in the electric field between a pair of conductors (called "plates"). The process of storing energy in the capacitor is known as "charging", and involves electric charges of equal magnitude, but opposite polarity, building up on each plate. A capacitor's ability to store charge is measured by its capacitance, in units of farads.

Capacitors are often used by engineers in electric and electronic circuits as energy-storage devices. They can also be used to differentiate between high-frequency and low-frequency signals. This property makes them useful in electronic filters.
A wide variety of capacitors have been invented, including small electrolytic capacitors used in electronic circuits, basic parallel-plate capacitors, mechanical variable capacitors and ceramic capacitors are among numerous other types of capacitors.

Ohm's Law

The relationship between Voltage, Current and Resistance in any DC electrical circuit was firstly discovered by the German physicist Georg Ohm. Ohm found that, at a constant temperature, the electrical current flowing through a fixed linear resistance is directly proportional to the voltage applied across it, and also inversely proportional to the resistance. This relationship between the Voltage, Current and Resistance forms the bases of Ohms Law

What is the exact relationship between Voltage, Current, and Resistance?

Here are two statements that describe the relationship:

1. Given a fixed Resistance, more Voltage causes more Current.

2. Given a fixed Voltage, more Resistance causes less Current.

(Before proceeding remember that we use Volts for electrical pressure, Amps for electrical current, and Ohms for resistance.)

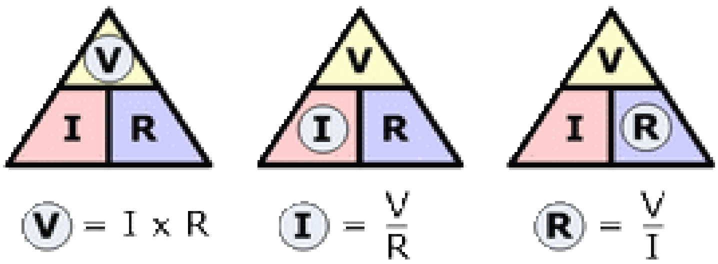
Ohm's Law is a set of three related equations that encapsulate the two statements above:

V= I X R   I = V / R   R = V / I

("V" to represent Voltage, "I" to represent Current, and "R" to represent Resistance.)

Ohm law triangle

It is sometimes easier to remember Ohms law relationship by using pictures. Here the three quantities of V, I and R have been superimposed into a triangle (called the Ohms Law Triangle) giving voltage at the top with current and resistance at the bottom. This arrangement represents the actual position of each quantity in the Ohms law formulas.



To calculate voltage, V: put your finger over V, this leaves you with I R, so the equation is V = I × R
To calculate current, I: put your finger over I, this leaves you with V over R, so the equation is I = V/R
To calculate resistance, R: put your finger over R, this leaves you with V over I, so the equation is R = V/I

Some Example Calculations

Using the Ohm's Law equations above we can analyze real-world circuits. Yes, it is math, but it is really fairly simple. Please don't give up until you have tried to understand the examples. Get out your calculator and follow along.

There are just three steps: First, choose the equation form where the facts you already know are on the right side and the answer you want is on the left side. Second, plug in your known values. Third, do the arithmetic.

Here are some examples using the same lamp circuit we have already looked at:

1. Suppose that our bulb has a resistance of 50 ohms and we know that it should be used with a current of 0.03 Amps. What battery voltage is needed?

We know the current and resistance and want to calculate the voltage, so we should choose the first equation (V= I * R)   then we calculate 50 * 0.03 which equals 1.5   so we need a 1.5V battery.

2. Now suppose that we have a 3 Volt battery and that our bulb has a resistance of 100 ohms. How much current is flowing when the bulb is lit?

We know the voltage and resistance and want to calculate the current, so we should choose the second equation (I = V / R)
we calculate 3 / 100 which equals 0.03
so 0.03 Amps of current is flowing.

3. Now suppose that we have a 4.5 V battery and that there is 0.03 Amps of current flowing. What is the bulb resistance?

We know the voltage and the current and want to calculate the resistance, so we should choose

the third equation (R = V / I)
and we calculate 4.5 / 0.03 which equals 150
so the bulb resistance is 150 ohms.

Kirchhoff's Laws - Current Law & Voltage Law

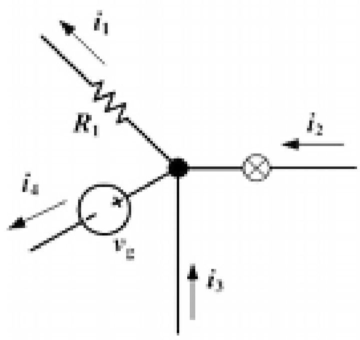
In 1845, German physicist Gustav Kirchhoff first described two laws that became central to electrical engineering. The laws were generalized from Ohm law . The following descriptions of Kirchhoff's Laws assume using a constant current. For time-varying current, or alternating current, the laws must be applied in a more complex method.

Kirchhoff's Current Law or the First Law

Kirchhoff's Current Law, also known as Kirchhoff's Junction Law and Kirchhoff's First Law, defines the way that electrical current is distributed when it crosses through a junction - a point where three or more conductors meet. Specifically, the law states that:
The algebraic sum of current into any junction is zero.

Since current is the flow of electrons through a conductor, it cannot build up at a junction, meaning that current is conserved: what comes in must come out. When performing calculations, current flowing into and out of the junction typically have opposite signs. This allows Kirchhoff's Current Law to be restated as:

The sum of current into a junction equals the sum of current out of the junction.



Kirchhoff's first Law in action

In the picture to the right, a junction of four conductors (i.e. wires) is shown. The currents i_2 and i_3 are flowing into the junction, while i_1 and i_4 flow out of it. In this example, Kirchhoff's Junction Rule yields the following equation:

$$\mathbf{i_2 + i_3 = i_1 + i_4}$$

Kirchhoff's Voltage Law or Second Law

Kirchhoff's Voltage Law describes the distribution of voltage within a loop, or closed conducting path, of an electrical circuit. Specifically, Kirchhoff's Voltage Law states that:

The algebraic sum of the voltage (potential) differences in any loop must equal zero.

The voltage differences include those associated with electromagnetic fields (emfs) and resistive elements, such as resistors, power sources (i.e. batteries) or devices (i.e. lamps, televisions, blenders, etc.) plugged into the circuit.

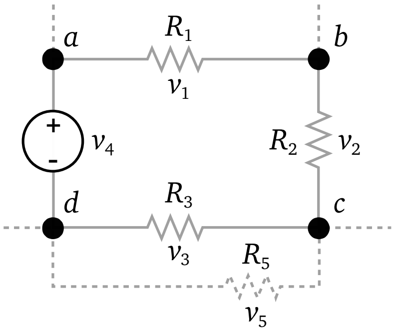
As you go around a loop, when you arrive at the starting point has the same potential as it did when you began, so any increases and decreases along the loop have to cancel out for a total change of 0. If it didn't, then the potential at the start/end point would have two different values.

Positive and Negative Signs in Kirchhoff's Voltage Law

Using the Voltage Rule requires some sign conventions, which aren't necessarily as clear as those in the Current Rule. You choose a direction (clockwise or counter-clockwise) to go along the loop.
When travelling from positive to negative (+ to -) in an emf (power source) the voltage drops, so the value is negative. When going from negative to positive (- to +) the voltage goes up, so the value is positive.

When crossing a resistor, the voltage change is determined by the formula I*R, where I is the value of the current and R is the resistance of the resistor. Crossing in the same direction as the current means the voltage goes down, so its value is negative. When crossing a resistor in the direction opposite the current, the voltage value is positive (the voltage is increasing).

Kirchhoff's Voltage Law in action



If the picture there is a loop **abcd** . If you begin at a and advance clockwise along the interior loop, the Voltage Law yields the equation:

$$v_1 + v_2 + v_3 + v_4 = 0$$

In this case, the current will also be clockwise. Crossing the resistors will result in v_1 , v_2 , and v_3 all being negative. Since you're crossing from negative to positive, v_4 will be positive. If you consider the dotted line that has the R_5 resistor, you get a total of three loops in the circuit. The first one has already been described. One loop is the largest loop and another is the smallest loop at the bottom, to yield the equations:

$v_1 + v_2 + v_5 + v_4 = 0$ (abcd taking the new path instead of R_5)

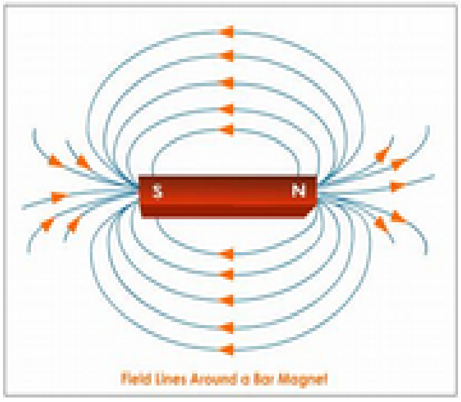
$v_3 + v_5 = 0$ (the small loop cd)

The second equation is of special interest, since it indicates that $v_3 = -v_5$. This makes sense, because both currents will be travelling from c to d , so on the small loop you'll cross one resistor with the current and the other resistor against the current. If the resistors are of equal value, then the current in both paths will be equal.

In the voltage loop diagram, we see that at junction c there are three conductors. Current enters from the top, then goes out in the other two directions and, from the Current Law, we know the algebraic sum of these must be zero. If we knew the resistance values of the resistors, and the current coming into the junction, we could use the Voltage Law equations to determine the currents in each of the lower paths, if the resistors were unequal.

Magnetism

What is a magnet?



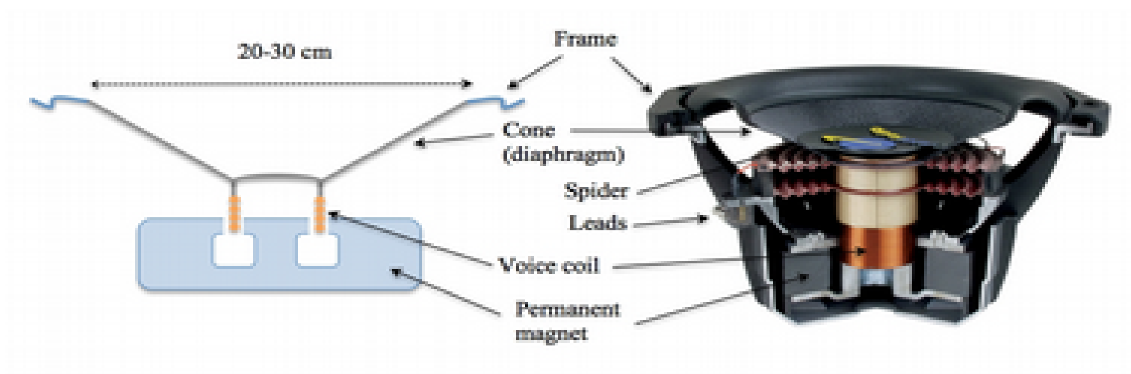
A piece of iron, nickel, cobalt, steel, alloy (e.g. alloy made from non-magnetic copper, manganese and aluminum) etc. usually in the form of a bar having properties of attracting or repelling iron is called a magnet. But what gives it its force is not completely known. One of the theories to describe magnetism is the-"Theory of Domains". It says that materials that can be made into magnets have many tiny crystal like structures called domains. Each domain is made up of many atoms. Each domain has a small magenetic force of its own. When the material is not magnetized, the domains are haphazardly arranged-pointing in all directions-so that their tiny forces cancel each other. To make the material into a magnet, the domains need to be lined up so that their individual magnetic forces all help each other pull the same way. When most of the domains line up, the magnet becomes strong. When all of the domains line up in one direction, the magnet is saturated. It cannot be made any stronger regardless of how much you try to magnetise it. In a magnetic bar, there are two poles: North and South. They are marked as ‘North’ and ‘South’ poles because, when the magnetic bar is suspended horizontally, one of the ends will always point towards the Earth’s geographical north and the other pole towards the Earth’s geographical south. This is because of the fact that the Earth itself behaves like a huge magnet. In a magnet, the like poles repel and the unlike poles attract-a reason for the specific alignment of the magnetic bar. The magnetic bar is surrounded by the invisible lines of forces which originate from the 'North' pole and terminate in the 'South' pole.

Ferro-magnet:

Iron, nickel and cobalt (including the alloy mentioned above) are considered ferromagnetic. Ferro-magnetic materials are difficult to be converted to magnet but once magnetized under the influence of another magnetic field, they cannot be completely demagnetized. Ferromagnetic materials are used to make permanent magnets. One of the strongest permanent magnets is a combination of iron, aluminum, nickel and cobalt called "Alnico".

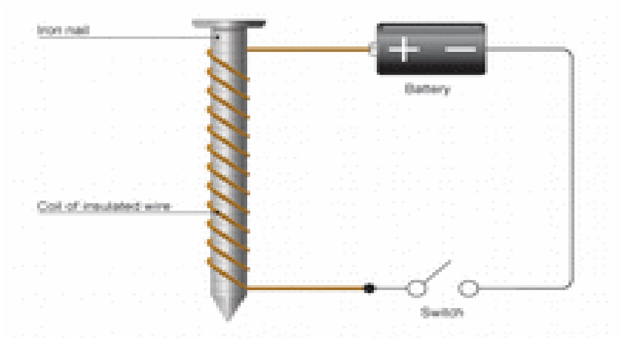
Use of Permanent magnets in Electronics:

Permanent magnets are used in electronics to make electric meters, headphones, loudspeakers,microphones, radar transmitting tubes etc.Electricity and electronics cannot be discussed by leaving apart 'magnetism' separately.



Electro-Magnet

We can create an electro-magnet by wrapping many turns of wire on a core, then causing an electrical current to flow through this coil of wire. With such a device we can create a magnetic field that can be controlled; we can turn it on and off by controlling the current. (In fact, by controlling the current gradually, instead of just on and off as shown here, we could make the magnetic field gradually become stronger or weaker.)



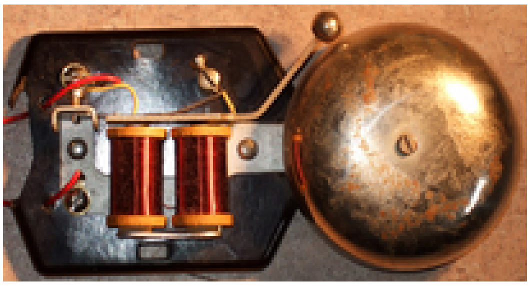
In the picture above, we are controlling the current by connecting and disconnecting the battery. When the battery is not connected, there is no current flow, and therefore no magnetic field. When the battery is connected, current flows through the coil, and a magnetic field is created, as shown by the lines. (In the real world, magnetic fields are invisible)

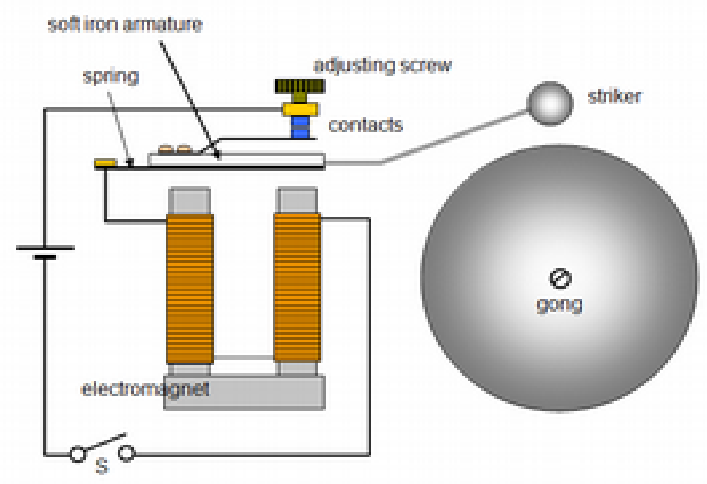
Note that the magnetic field curves around from one end of the coil to the other. The field is strongest at the ends of the coil, and gets weaker as we get farther away. We call the two ends of the coil the "poles". In fact, one is "North" and the other is "South" just like any other magnet.

If we use iron or steel as the core of our electro-magnet, the field at the poles will be stronger. In some sense, the magnetic field is "focussed" by the presence of these materials.

The strength of the field is proportional to the amount of current flowing and to the number of turns on the coil. Each turn of wire on the coil contributes to the strength of the magnetic field. If we double the number of turns, we can make an electro-magnet twice as strong. But, this exact ratio is only true if the current flow is the same for both coils!

An electrical bell, How it works?





See the figure,When the switch is pushed closed the circuit is completed and current flows through the electromagnetic coil.

1. The iron striker is attracted to the electromagnet and strikes the bell.
2. As the striker moves towards the bell,the contact is broken. Electricity stops flowing through the coil which loses its magnetism.
3. The spring returns the striker to its original position which makes a new contact and so electricity flows again.
4. Back to number 1 and the cycle repeats itself. The bell will continue to ring as long as the switch is held closed.

Self inductance and Mutual inductance

Self inductance

The phenomenon of self-induction was first recognized by the American scientist Joseph Henry. He was able to generate large and spectacular electric arcs by interrupting the current in a large copper coil with many turns.

Self induction is that phenomenon in which a change in electric current in a coil produces an induced emf in the coil itself. Self induced emf in a coil is directly proportional to the rate of change of electric current in the coil.i.e.

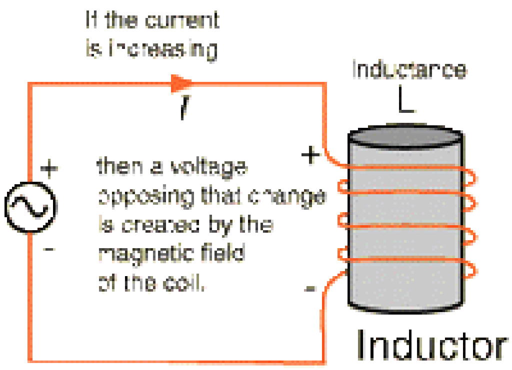
Or **emf = -L (dI/dt)**

Where, **L** = self inductance of the coil.

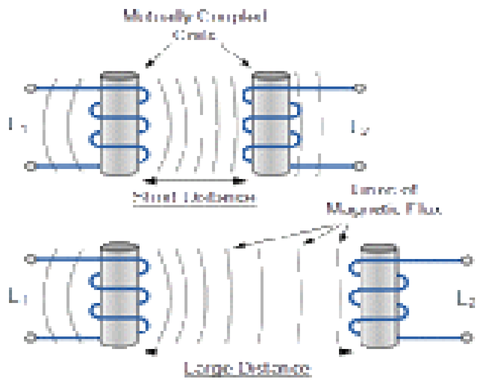
Self inductance of a coil is defined as the ratio of self-induced emf to the rate of change of current in the coil.

Self inductance = emf/(dI/dt)

It is denoted by 'L' and it depends upon the physical characteristics of the coil. Unit of self inductance is Henry.



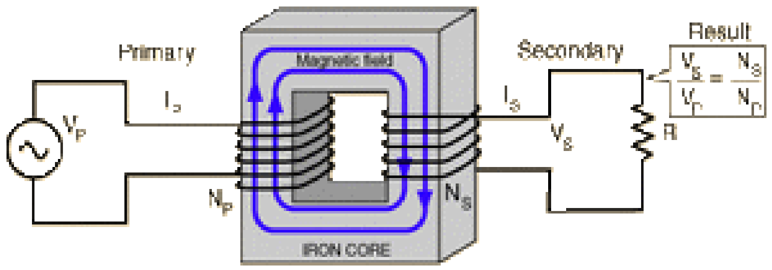
Mutual Inductance



In the previous tutorial we saw that an inductor generates an induced emf within itself as a result of the changing magnetic field around its own turns, and when this emf is induced in the same circuit in which the current is changing this effect is called Self-induction, (L).

However, when the emf is induced into an adjacent coil situated within the same magnetic field, the emf is said to be induced magnetically, inductively or by Mutual induction, symbol (M). Then when two or more coils are magnetically linked together by a common magnetic flux they are said to have the property of Mutual Inductance.

Mutual Inductance is the basic operating principal of the transformer, motors, generators and any other electrical component that interacts with another magnetic field. Then we can define mutual induction as the current flowing in one coil that induces an voltage in an adjacent coil.



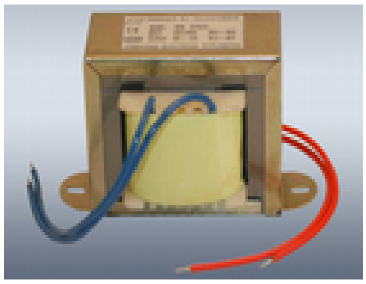


Figure above illustrates the configuration of a typical transformer. Here, coils of insulated conducting wire are wound around a ring of iron constructed of thin isolated laminations or sheets. The laminations minimize eddy currents in the iron. Eddy currents are circulatory currents induced in the metal by the changing magnetic field. These currents produce an undesirable by-product—heat in the iron. Energy loss in a transformer can be reduced by using thinner laminations, very “soft” (low-carbon) iron and wire with a larger cross section, or by winding the primary and secondary circuits with conductors that have very low resistance. Unfortunately, reducing the heat loss increases the cost of transformers. Transformers used to transmit and distribute power are commonly 98 to 99 percent efficient. While eddy currents are a problem in transformers, they are useful for heating objects in a vacuum. Eddy currents are induced in the object to be heated by surrounding a relatively nonconducting vacuum enclosure with a coil carrying a high-frequency alternating current.

In a transformer, the iron ensures that nearly all the lines of magnetic flux passing through one circuit also pass through the second circuit. So that each turn of the conducting coils has the same magnetic flux; thus, the total flux for each coil is proportional to the number of turns in the coil. As a result, if a source of sinusoidally varying electromotive force is connected to one coil, the electromotive force in the second coil is given by

$$\frac{\text{Voltage in Secondary Coil}}{\text{Voltage in Primary Coil}} = \frac{\text{Turns on Secondary Coil}}{\text{Turns on Primary Coil}}$$

OR

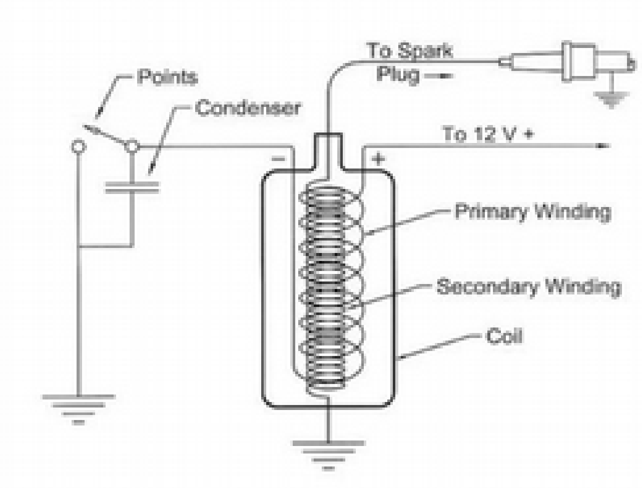
$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

Thus, depending on the ratio of Ns to Np, the transformer can be either a step-up or a step-down device for alternating voltages. For many reasons, including safety, generation and consumption of electric power occur at relatively low voltages. Step-up transformers are used to obtain high voltages before electric power is transmitted, since for a given amount of power, the current in the transmission lines is much smaller. This minimizes energy lost by resistive heating of the conductors.

Ignition coil

An ignition coil (also called a spark coil) is an induction coil in an automobile's ignition system which transforms the battery's low voltage to the thousands of volts needed to create an electric spark in the spark plugs to ignite the fuel. The wire that goes from the ignition coil to the distributor and the high voltage wires that go from the distributor to each of the spark plugs are called spark plug wires or high tension leads.

How an Ignition coil in a petrol engine system works



An ignition coil consists of a laminated iron core surrounded by two coils of copper wire. Unlike a power transformer, an ignition coil has an open magnetic circuit - the iron core does not form a closed loop around the windings. The energy that is stored in the magnetic field of the core is the energy that is transferred to the spark plug.

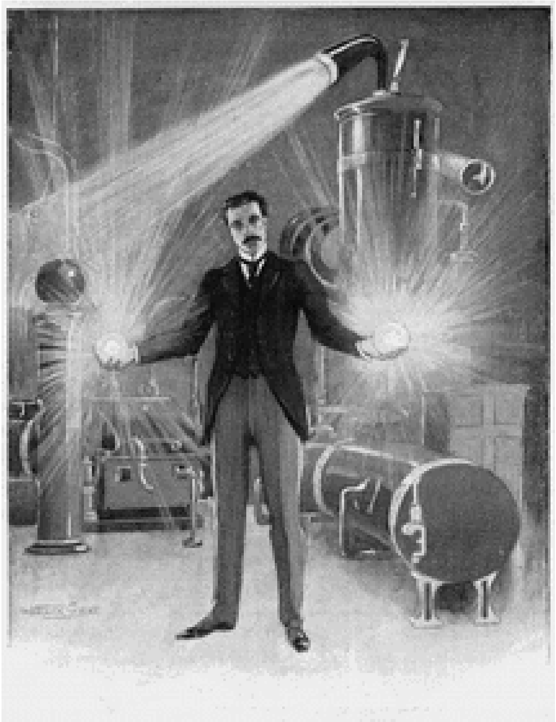
The primary winding has relatively few turns of heavy wire. The secondary winding consists of thousands of turns of smaller wire, insulated for the high voltage by enamel on the wires and layers of oiled paper insulation. The coil is usually inserted into a metal can or plastic case with insulated terminals for the high voltage and low voltage connections. When the contact breaker closes, it allows a current from the battery to build up in the primary winding of the ignition coil. The current does not flow instantly because of the inductance of the coil. Current flowing in the coil produces a magnetic field in the core and in the air surrounding the core. Once the current has built up to its full level, the contact breaker opens. Since it has a capacitor connected across it, the primary winding and the capacitor form a tuned circuit, and as the stored energy oscillates between the inductor formed by the coil and the capacitor, the changing magnetic field in the core of the coil induces a much larger voltage in the secondary of the coil. The timing of the opening of the contacts (or switching of the transistor) must be matched to the position of the piston in the cylinder. The spark must occur after the air/fuel mixture is compressed. The contacts are driven off a shaft that is driven by the engine crankshaft, or, if electronic ignition is used, a sensor on the engine shaft controls the timing of the pulses.

Tesla Coil

A Tesla coil is an electrical resonant transformer circuit invented by Nikola Tesla around 1891. It is used to produce high-voltage, low-current, high frequency alternating-current electricity.

Tesla used these coils to conduct innovative experiments in electrical lighting, phosphorescence, X-ray generation, high frequency alternating current phenomena, electrotherapy, and the transmission of electrical energy without wires. Tesla coil circuits were used commercially in sparkgap radio transmitters for wireless telegraphy until the 1920s, and in medical equipment such as electrotherapy and violet ray devices. Today their main use is for entertainment and educational displays, although small coils are still used today as leak detectors for high vacuum systems.

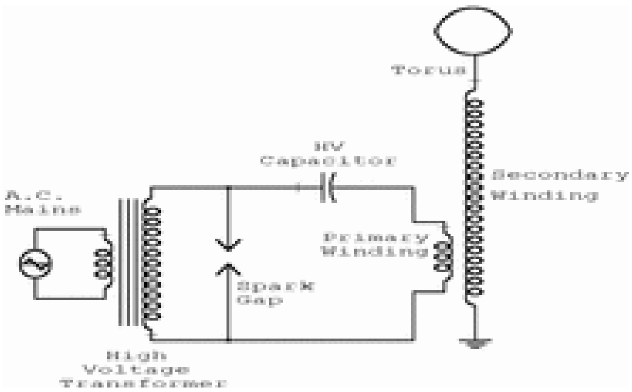
The Tesla coil is one of Nikola Tesla's most famous inventions. It is essentially a high-frequency air-core transformer. It takes the output from a 120vAC to several kilovolt transformer & driver circuit and steps it up to an extremely high voltage. Voltages can get to be well above 1,000,000 volts and are discharged in the form of electrical arcs. Tesla coils are unique in the fact that they create extremely powerful electrical fields. Large coils have been known to wirelessly light up florescent lights up to 50 feet away, and because of the fact that it is an electric field that goes directly into the light and doesn't use the electrodes, even burned-out florescent lights will glow.



Nikola Tesla holding in his hands balls of flame

A Tesla coil transformer operates in a significantly different fashion from a conventional (i.e., iron core) transformer. In a conventional transformer, the windings are very tightly coupled and voltage gain is determined by the ratio of the numbers of turns in the windings. This works well at normal voltages, but, at high voltages, the insulation between the two sets of windings is easily broken down and this prevents iron-cored transformers from running at extremely high voltages without damage.

Unlike those of a conventional transformer (which may couple 97%+ of the fields between windings), a Tesla coil's windings are "loosely" coupled, with a large air gap, and thus the primary and secondary typically share only 10–20% of their respective magnetic fields. Instead of a tight coupling, the coil transfers energy (via loose coupling) from one oscillating resonant circuit (the primary) to the other (the secondary) over a number of radio frequency cycles.



As the primary energy transfers to the secondary, the secondary's output voltage increases until all of the available primary energy has been transferred to the secondary (less losses). Even with significant spark gap losses, a well-designed Tesla coil can transfer over 85% of the energy initially stored in the primary capacitor to the secondary circuit. The voltage achievable from a Tesla coil can be significantly greater than a conventional transformer, because the secondary winding is a long single layer solenoid widely separated from the surroundings and therefore well insulated. Also, the voltage per turn in any coil is higher because the rate of change of magnetic flux is at high frequencies.

With the loose coupling the voltage gain is instead proportional to the square root of the ratio of secondary and primary inductances. Because the secondary winding is wound to be resonant at the same frequency as the primary, this voltage gain is also proportional to the square root of the ratio of the primary capacitor to the stray capacitance of the secondary.