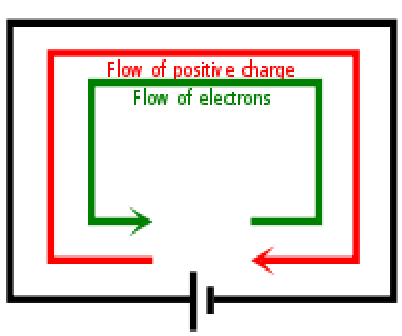
Basic Electronics Syllabus - 005 Series

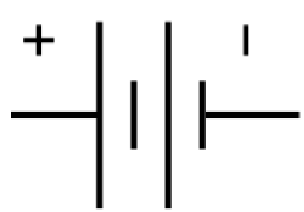
5-1 Metric Prefixes.

- **kilo (k)** means 1,000 (thousand) of the basic units, e.g. 3.3 k ohms resistor = 3300 ohms resistance or 3.3×10^{3} ohms.
- **mega (M)** means 1,000,000 (million) of the basic units, e.g. 3.620 MHz = 3,620,000 Hz or 3620 kHz.
- **giga (G)** means 1,000,000,000 (1,000 Million) of the basic units, e.g. 1296 MHz = 1.296 GHz.
- **milli (m)** means one thousandth of the basic units, e.g. 0.005 amperes = 5 milliamps or 5 mA or 5×10^{-3} amperes.
- **micro (u)** means one millionth of the basic units, e.g. 1 uV = 0.000001 volts or 1×10^{-6} volts.
- **nano (n)** means one thousandth of one millionth of the basic units, e.g. 12 nF = 0.000000012 Farads (of capacitance) or 12×10^{-9} Farads.
- **pico (p)** means one millionth of one millionth of the basic units, e.g. 220 pF of capacitance = 0.000 000 000 220 Farads or 220×10^{-12} Farads.

5-2 <u>Concepts of atomic theory, electron flow, current, voltage, conductors, insulators, resistance, conductance, sources of DC (direct current), batteries</u>

- **<u>Most metals are good conductors or electricity</u>**. This means in such materials, it is relatively easy to dislodge some of the valence electrons.
- When it is very difficult to dislodge valence electrons in certain types of materials, these are known as **<u>insulators</u>** and **<u>do not conduct electricity well</u>**.
- **<u>The three best conductors</u>** in relative order are: **<u>silver, copper, aluminum</u>**. Copper and aluminum are commonly used as electrical wire conductors based on cost and weight advantages.
- Common **<u>insulator materials</u>** are : **<u>plastics and rubber, porcelain, ceramics, mica, glass, and treated dry wood.</u>**
- The direction of conventional current is arbitrarily defined to be in the same direction as the flow of positive charges; however, in metals (and conductor wiring in electrical circuits) positive charges are immobile and the charge carriers are electrons.





Symbol of a Battery

- **Electron flow is from negative to positive polarity of a voltage source.**

- **Voltage** is a measure of the electrical **tension (or pressure)**, or electrical potential difference between two points in an electrical circuit. From a source of energy, voltage can be referred to as the "Electromotive Force" or EMF. Using an analogy to water flowing through a pipe, voltage is like the water pressure in the pipe. The "Volt" is the International Standard Unit of measure for Voltage or V. It is also referred by the **symbol "E"** for EMF in electrical equations such as Ohm's Law.

- Current in an electrical circuit is the **amount of electrons** flowing in a conductor (wire). This can be compared similarly to the amount (volume) of water flowing in a water pipe.

- The **Ampere (A)** is the International Unit measure of Current in an electrical circuit. The letter **" I "** is often used as the symbol for current in electrical equations involving **"Ohm's Law"** calculations.

- **Resistance** is the third basic element of measure in an electrical circuit. The International Standard Unit of measure for electrical resistance is the **Ohm**. As the term implies, resistance in an electrical circuit is that quality of a material that resists the free flow or conductance of electrons. In our water pipe analogy, electrical resistance would be similar to the diameter of a water pipe; the narrower the pipe, the greater the "resistance" to the flow of water. The letter **"R"** is used as the symbol for resistance in electrical equations involving **"Ohm's Law".**

- Electrical **Conductance** is the inverse to the electrical **Resistance.** The Unit of electrical conductance is the **Siemen (S)** but used to be known as the Mho. S = 1/R .

- All materials (above absolute zero in temperature) have varying degrees of resistance to electricity flow. Actual devices manufactured for electrical / electronic circuits having defined resistance are called **Resistors**; these devices are most often made with a **Carbon** composite material or thinly wound “Nichrome” wire.

- **The resistance in an electrical conductor changes with temperature**. The resistance often decreases at very cold temperatures.

- **Sources of Direct Current (DC) include batteries, solar panels, thermoelectric effect, AC to DC power supplies, etc.**

- **Primary Cell batteries** are designed to be used and recycled; **they cannot be recharged**. **Secondary Cells are designed to be charged and discharged over many cycles**.

- Examples of **Primary Cell battery** technologies are **Zinc Carbon**, **Alkaline**, and use once **Lithium** cells.

- Examples of **Secondary Cell** technologies are **Lead Acid**, **Lithium Ion**, **Lithium Polymer**, and **Nickel Cadmium**.

5-3 Concepts of Energy and Power, Open and Short circuits

- **Electric power is the rate at which electric energy is transferred by an electric circuit**. The **International Standard Unit for power is the Watt** and is equal to one joule of energy per second.

- Electrical energy cannot be created but only results from conversion of other forms of energy and cannot be destroyed but can be transformed , again, to other forms such as thermal (heat) or mechanical energy.

- Light bulbs are electrical devices that convert electric energy into light (photon kinetic energy) and heat energy. Light bulbs are therefore typically rated in Watts which represents the rate of such electrical energy transfer.

- We typically pay for electrical consumption at a rate of price per **KiloWatt / hours** from the electric power company.

- When an electrical circuit is an **Open Circuit**, there is **no closed path of conduction** and therefore **No Current flows** in the circuit. Under this condition, there is no electric energy transferred.

- A **Short Circuit** is the opposite to an Open Circuit. The term **Short Circuit** refers to a condition in an electrical circuit where **too much current flows** typically as a result of a fault that allows the current flow to bypass the normal circuit current paths that are properly resistance limited.

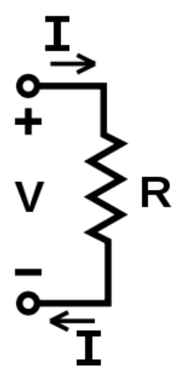
- In an electrical circuit, the amount of **power** consumed and converted to other forms of energy is equivalent to **Voltage** applied to the circuit **multiplied** by the **current flow** in the circuit. **P = V x I or (power in watts = voltage (in Volts) X current (I in Amperes)**

- In electrical circuits, **current flowing through a Resistor device will convert electrical energy into heat.** The **rate of this energy conversion** is expressed as **power in Watts** and is equivalent to **(the amount of current flow in Amperes squared) multiplied by (the resistance of the resistor device in Ohms) or as an equation: $P = I^2 \times R$.**

- If the **<u>voltage across a resistor device</u>** is known, the **<u>power (P in Watts)</u>** dissipated as heat by resistor is expressed as the equation: **<u>$P = V^2 / R$ (voltage in Volts across the resistor squared divided by the resistance value of the resistor in Ohms).</u>**

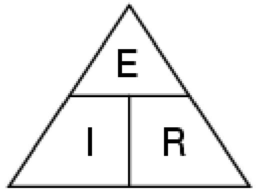
5.4 <u>Ohm's Law - single resistors</u>

- **<u>Ohm's Law</u>** deals with the **<u>relationship</u>** between **<u>voltage (V) and current (I)</u>** in an ideal conductor where there is a constant of proportionality called **<u>Resistance (R).</u>**

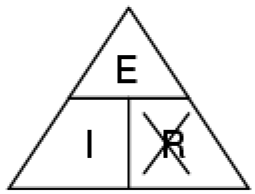


- In the above simple circuit, the amount of current (I) in Amps flowing through the resistor (R) is determined by the value of the voltage in Volts divided by the value of the resistance of the resistor (R) in Ohms. ***<u>I = V / R ; this may also be expressed as I = E / R</u>***

- **<u>Ohm's Law</u>** is the most basic of electrical circuit analysis equations; knowing two of the circuit conditions, the third can be determined based on the **<u>Ohm's Law triangle</u>**:

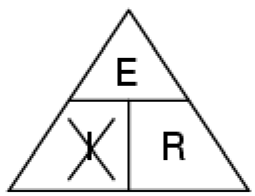


- If you know E and I , and wish to determine R



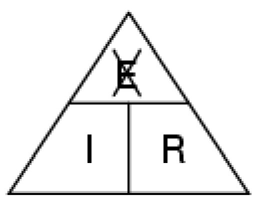
$$R = \frac{E}{I}$$

- If you know E and R, and wish to determine I



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

- And, if you know I and R, and wish to determine E, then



$$E = I\,R$$

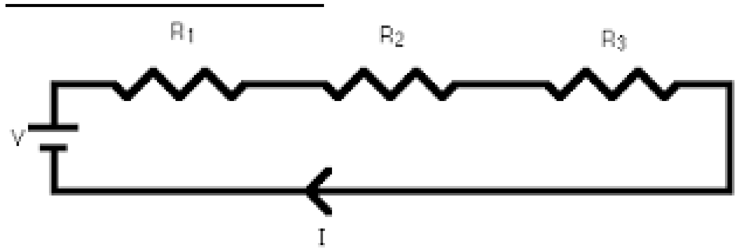
- The relationships of Voltage, Current and Resistance in a circuit is nicely shown in at the following URL : http://phet.colorado.edu/sims/html/ohms-law/latest/ohms-law_en.html

- A actual exam question on this section is: " *If a 12-volt battery supplies 0.25 amperes to a circuit, what is the circuit's resistance?"* Applying the Ohm's Law equation: R = E / I . R (in ohms) = E (12 volts) / I (0.25 Amps) = 48 ohms

- Another actual exam question on this section is: *"Calculate the value of resistance necessary to drop 100 volts with a current flow of 0.8 milliamperes."* Applying the Ohm's Law equation: R = E / I E (in volts) = 100 volts divided by 0.8 x 10^{-3} Amperes = 125 x 10^{3} = 125000 ohms = 125 K ohms.

5. 5 Resistors in Series and Parallel

- **Resistors in Series**

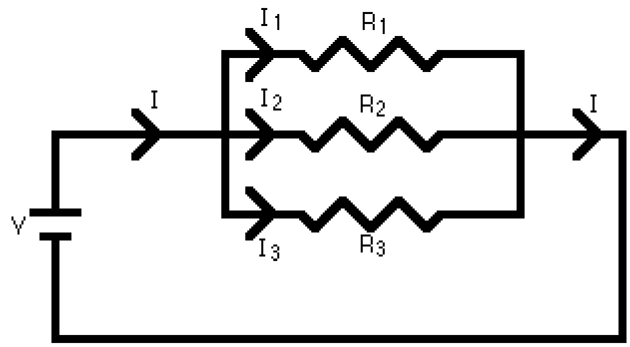


- The total resistance in the above circuit is equal to: **R1 + R2 + R3**

- An actual exam question in this section is: "*Five 10 ohm resistors connected in series equals":* 10 + 10 + 10 + 10 + 10 = 50 ohms.

- Another question is: *"The total resistance of resistors connect in series is:"* and the right answer is given as *"greater than the resistance of any one resistor*".

- **<u>Resistors in Parallel</u>**



- To calculate the equivalent resistance of resistors in parallel is given by the equation:

$$\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}.$$

- If the resistors in parallel **<u>are of equal value</u>**, then to calculate the equivalent resistance is given by the simpler equation:

$$R_{\text{total}} = \frac{R}{N}.$$

where N is the number of equal value resistors in parallel.

- All exam questions for resistors in parallel will involve resistors of equal value and will allow using the simpler equation above.

5. 6 <u>Power law, Resistor Power Dissipation</u>

- As given before, the electrical power consumed by an electrical device or equipment is the product of the voltage applied to the device or equipment and the current drawn by the device or equipment. **P = E x I** (P=power, E=voltage, I=current)

- Resistors are electrical devices that by virtue of having resistance convert electrical power into heat while performing their functions to limit current flow in parts of an electronic circuit and thus establish prescribed circuit voltages based on proper design criteria.

- Resistors are designed to be physically big or small depending whether their operation must dissipate a large or small amount of power.

- Besides the resistance value of a resistor, resistor components are rated in the amount of power, in **<u>watts</u>**, that the device can safety dissipate without becoming too hot.

- If a resistor device is called to dissipate too much power by virtue of the voltage across it multiplied by the current flowing through it (based on Ohm's Law calculations) the temperature of the device may get too hot and burn and be destroyed.

- Small component resistors used in electronic circuits will have a power dissipation rating of 1/8 or 1/4 or 1/2 or 1 watt or more. Each of these power dissipation ratings will be a resistor device with progressively bigger in physical size.

- An actual question from the exam bank in this section reads: ***"The DC input power of a transmitter operating at 12 volts and drawing 500 milliamperes would be":*** Answer is determined by P = E x I equates to P = 12 volts x 500 x 10^{-3} amperes = 6000 milliwatts or ***6 watts.***

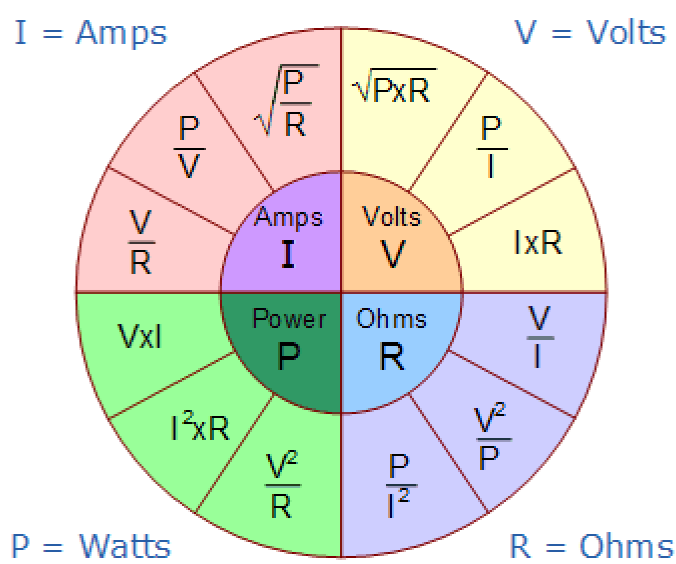
- Resistors of the same value and same power rating whether connected in series or connected in parallel will have an total power dissipation capability of their total.

- Example and actual question from the question bank for this section: "***When two 500 ohm, 1 watt, resistors are connected in series, the maximum total power that can be dissipated by the resistors is:*** Answer is **" 2 watts".**

- Or another actual question is: ***"If the voltage applied to two resistors in series is doubled, how much will the total power change?"*** Answer is ***"Increase four times"*** **$P = V^2 / R$**

- Some special resistors are called to dissipate large amounts of power such as a **RF "Dummy Load"** for connection to the output of transmitter undergoing tests and adjustments; such resistors are often bathed in mineral oil in a container to help absorb and transfer the heat from the resistor element.

- **Resistors** are typically **identified in Resistance value** by **Colour Coding**; this will be discussed in detail in the **Section 004 "Circuit Components"**



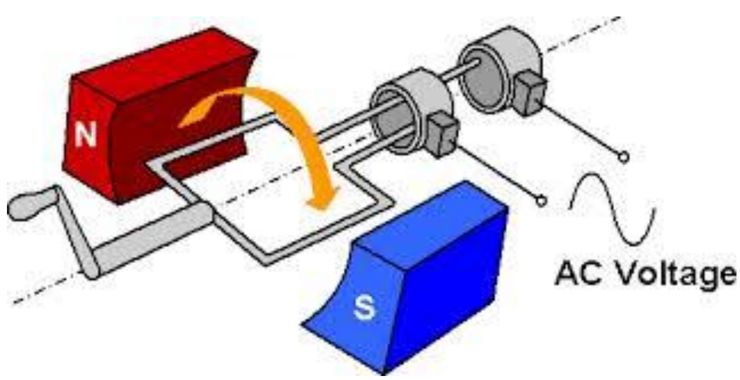
5- 7 AC (alternating current), AC generation, Sine Wave, Frequency, Frequency units, RMS units, AC vs DC

- In **alternating current (AC),** the flow of electric charge periodically reverses direction as opposed to direct current (DC), where the flow of electric charge is only in one direction.

- The **rate of change** in the direction of the flow of electric charge of **AC is called the frequency in cycles per second**. The International System of Units for the AC frequency is the **"Hertz (Hz)"** named after Heinrich Rudolf Hertz who first conclusively proved the existence of electromagnetic waves. **One Hertz (Hz) is the same as One Cycle Per Second** of Alternating Current change in direction.

- Our electric power system grid is Alternating Current maintained at 60 Hz (exactly).

- AC power generation is produced with large electro-mechanical "Alternators" powered by a variety of energy sources.

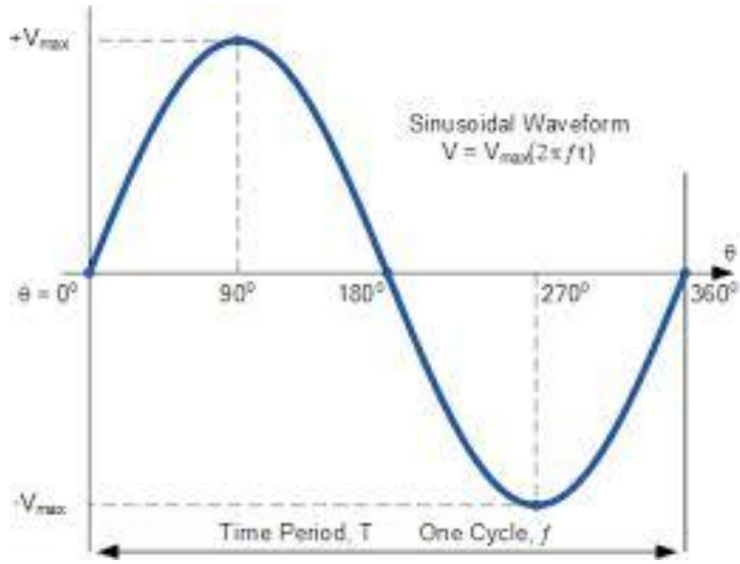


- AC power can also be generated by means of electronic switching or oscillating systems.

- A **simple radio transmitter is just an AC power generator** (at some defined power) operating at prescribed "Radio Frequencies" and connected to an antenna system that "radiates" the energy in the form of "Electromagnetic Waves"

- The **human ear** can hear **acoustic wave oscillations** in the range of **20 to 20,000 Hz**. (most older folks have lost their higher frequency hearing)

- The typical waveform of AC power generation is the "Sine Wave". The sine wave or sinusoid is a mathematical curve that describes a smooth repetitive oscillation. The human ear can recognize single acoustic sine waves as sounding clear because sine waves are representations of a single frequency with no harmonics. A good tuning fork generates a pure sine wave.



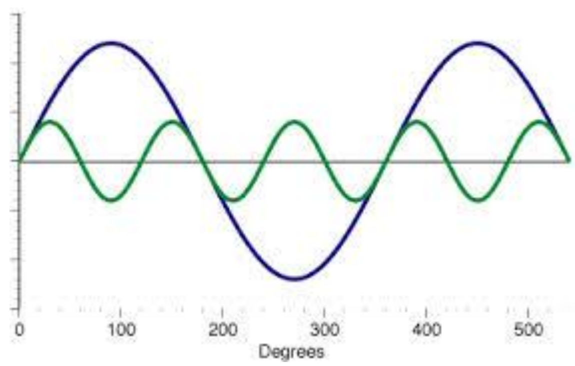
- The **time taken for one cycle** of the waveform to complete is known as **<u>the period.</u>** The period is calculated as **<u>1/frequency</u>** and the knowing the period, the **<u>frequency</u>** can be calculated as **<u>1/period</u>**.

- As the frequency increases, the period decreases and vice versa.

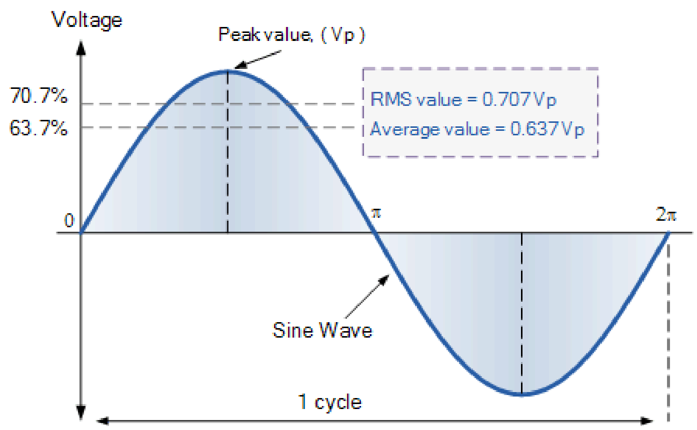
- An exam question in this section is: *"The current in an AC circuit goes through a complete cycle in 0.1 seconds. This means the AC has a frequency of:* The answer is calculated as 1/period = 1 / 0.1 seconds = *10 Hz*.

- Distortions in a sine wave cause harmonics of the fundamental frequency. The second harmonic is the twice the fundamental frequency, the third harmonic is three times the fundamental frequency and so on.

- As shown in the diagram the fundamental and third harmonic. Note there are 3 completed cycles of the 3rd harmonic shown in green for one completed cycle of the fundamental shown in blue.



- **<u>RMS (Root Mean Square)</u>** value of the **<u>Sine Waveform</u>**. When AC current that is pulsing back and forth as a Sine wave function is applied to a resistor, we need to know the effective power that will result as dissipated heat in a resistor. This is essentially determine as the area under the curve of the waveform. For a sine wave AC current flow, the **<u>effective power</u>** as heating of a resistor is the square root of the mean of the squares of the instantaneous values taken over a complete cycle of the waveform which is simply calculated as **<u>0.707 of the peak value of the waveform.</u>**



- AC Volt and Amp meters, as a default, are calibrated in RMS values.

5-8 Ratios, Logarithms, Decibels

- The decibel (dB) is a logarithmic unit used to express the ratios between two values of a physical quantity, often for power comparison or intensity.

- In electronics and radio, the gains of amplifiers, the gain of antennas, attenuation of signals and signal-to-noise ratios are most often expressed in decibels.

- The ratio of two power levels, P1 and P2 , is calculated as a decibel difference by the equation 10 $\log_{10}$ P1/P2

- If we are dealing with increasing the power of a radio transmitters from 1 watt to 10 watts, the dB increase is calculated as 10 $\log_{10}$ 10/1 = 10 dB

- A change of power by a factor of 2 approximately corresponds to a 3 dB change. Equation = 10 $\log_{10}$ 2/1 = 3.010299957 dB or 3 dB rounded.

- For power, 2 x = 3 dB, 4 x = 6 dB, 10 x = 10 dB, 100 x = 20 dB, 1000 x = 30 dB

- A +1 dB change amounts to approximately 26% increase in power. A -1dB change amounts to approximately 26% decrease in power.

- Instead of power, when dealing with voltage or current when the impedance (AC resistance) is held constant, dB ratios are expressed as the equation : 20 $\log_{10}$ V1/V2 or 20 $\log_{10}$ I1/I2. Doubling the voltage (or current) in a circuit amounts to approximately a 6 dB change in power.

- On a communications receiver, the "S" (signal strength) meter is often calibrated in dB above S 9. <u>Each "S" unit is equivalent to 6 dB.</u>

- dB ratios are often referenced to Absolute values. Common examples are:
    - **dBm** is dB above (or below as a minus) **1 milliwatt**, (e.g. 30 dBm = 1 watt)
    - **dBw** is dB above (or below as a minus) **1 watt**, (e.g. 30 dBw = 1000 watts)

- **dBd** is dB gain of an antenna with **reference to a simple dipole antenna**
- **dBi** is dB gain of an antenna with reference to an **isotropic radiator**

5-9 Introduction to Inductance and Capacitance

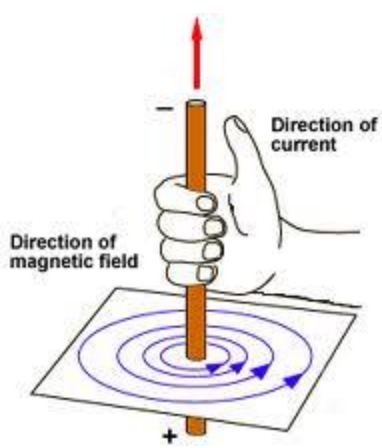
and

5-10 Introduction to Reactance and Impedance.

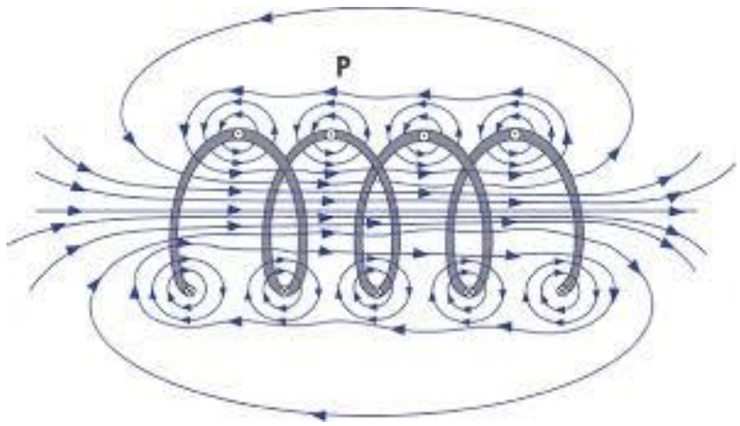
- Inductance and Capacitance play a big part in Radio Technology.

Inductance and Inductors.

- Every wire or conductor will inherently have a degree of inductance as a result of the magnetic field around it when electric current flows through it.



- The inductance can be greatly increased by winding the conductor in the form of a coil.

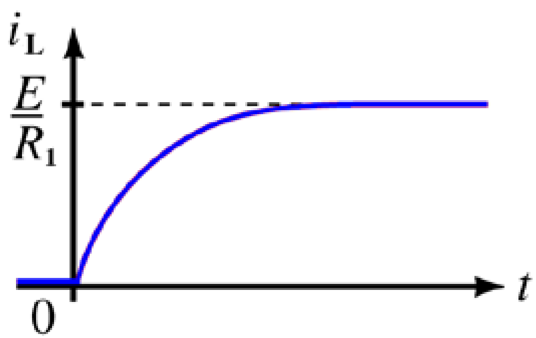


- The inductance can further be increased by having the core of the coil wound around a magnetic core material such as iron used to confine and guide the magnetic field. The measure of the ability of a material to support the formation of a magnetic field within itself is called "Permeability" and different (magnetic) materials will have different measures of this characteristic.

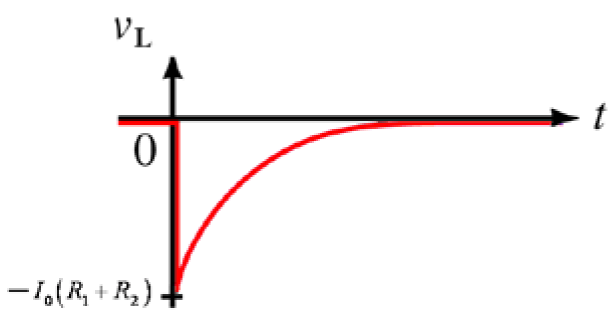
- **Inductors that are close to each other** so that the lines of magnetic field generated by one coil induce currents in the other coil are said to be in **Mutual Inductance**.

- A coil of wire is sometimes called a **solenoid** when its purpose is to draw into itself, an iron plunger for some electro mechanical purpose such as ringing a door bell. Or, a coil with a iron core will become an **electro magnet** with a variety of purposes such as **actuating an electro mechanical switch called a relay.**

- A conductor having inductance when a voltage is applied to it, will immediately oppose the build up of current in the circuit countered by a reverse electromotive force (EMF or voltage) by the build up of a magnetic field around the conductor.



- Conversely, when an electric current is removed from an inductive circuit, the collapse of the magnetic field around it will create an induced and opposite voltage across the inductor than that, that was initially applied.



- These effects indicate that **<u>an inductor is a transient store of energy.</u>**

- These **characteristics of inductance have a profound effect when inductance is used in AC circuits** which are constantly changing direction of current flow.

- The **unit of measure of Inductance** is the **"Henry";** it is defined as: If the rate of change of current in a circuit is one ampere per second and the resulting electromotive force is one volt, then the inductance of the circuit is one Henry.

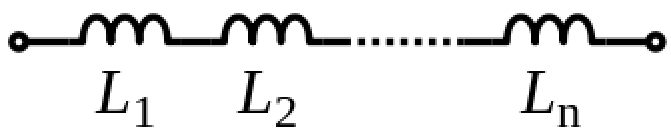
- **Inductors behave in AC circuits to resist the AC current flow as a resistor would also do so**, but unlike a resistor, the amount of resistance (**for AC called reactance**) is now **proportional** to the amount of **Inductance (in Henrys)** and **the frequency in Hertz**. The formula for calculating inductive reactance is:

$$X_L = 2\pi fL.$$

  - where X_L is the inductive reactance in ohms
  - where f is the frequency in Hertz
  - where L is the inductance in Henrys
  - and the symbol π equals 3.14

- In this way, inductors can serve as frequency selective devices allowing DC and low frequency AC currents to flow but suppressing higher frequencies.

- When **<u>inductors are connected in series,</u>** the **<u>total inductance</u>** in Henrys is the **<u>sum of the individual inductors</u>**. This is the same for resistors.



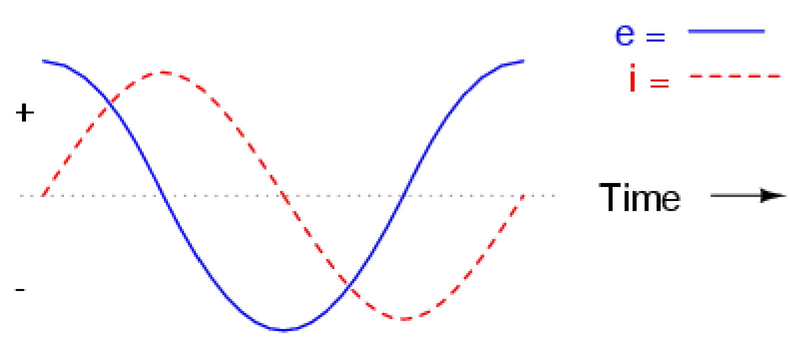
$$L_{total} = L_1 + L_2 + \cdots + L_n$$

- When inductors are connected in parallel, the calculation is the same as calculating resistors in parallel :

Parallel Inductances

$$L_{total} = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \ldots \frac{1}{L_n}}$$

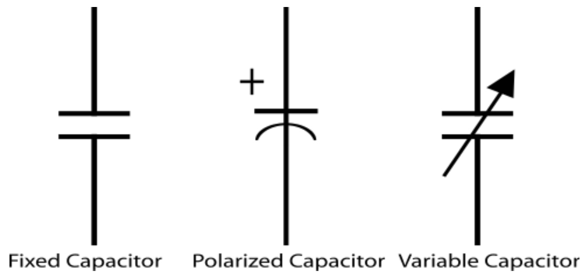
- When inductors are placed in an AC circuit, as opposed to a DC circuit, the current is not in sync with the voltage applied, in fact current lags the voltage by 90 degrees.



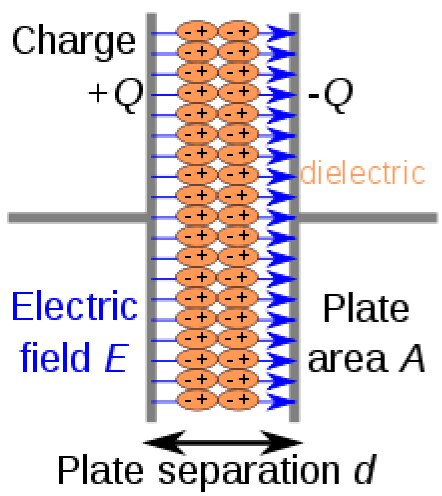
- **<u>Capacitance and Capacitors.</u>**

- A capacitor is a passive two-terminal electrical component used to store energy electrostatically in an electric field.

- The electronic symbols for capacitors are:



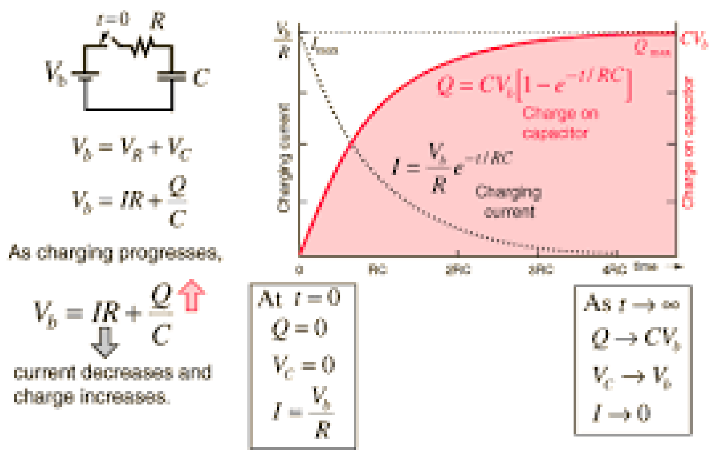
- As the symbols would suggest, capacitors contain at least two electrical conductors (or plates) separated by a non-conductive region called a dielectric insulating material such as air, a vacuum, paper, mica, plastic film, ceramic, etc.



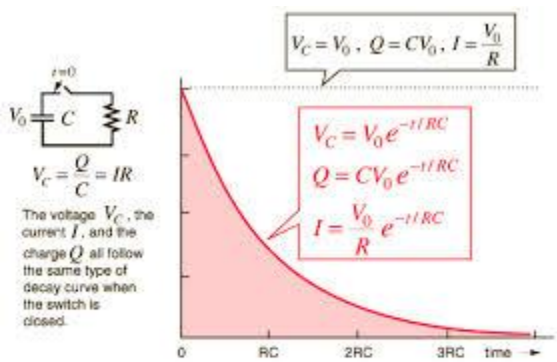
Even twisting two <u>insulated</u> wires together would form a capacitor where the wire insulation would be the dielectric.

- If a DC potential difference (from a battery or otherwise) is connected to a capacitor, an electric current will flow until a positive charge fully accumulates on one plate and a negative charges collects on the other plate resulting in no continuing current flow.

- Charging a capacitor:

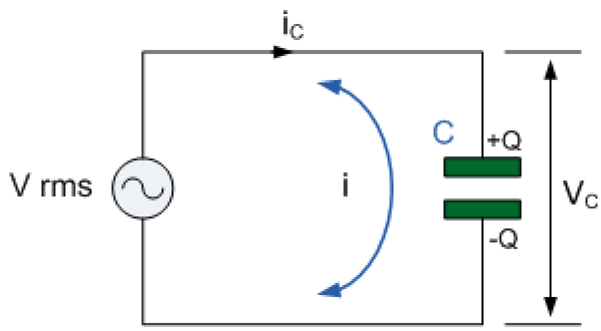


- And discharging a capacitor:



- Removing the DC "charging " potential from the capacitor, the charge on the plates will remain until it is drained by connecting an electrical load such as a resistor. In this way, a capacitor is a store of electrical energy and therefore can be considered as a mini battery.

- If however, a time-varying voltage (such as AC) is applied across a capacitor, a displacement current can flow.



- Capacitors are like Inductors in that they have a reactance to the flow of AC current depending on the frequency of the AC but inversely so (compared to an inductor).

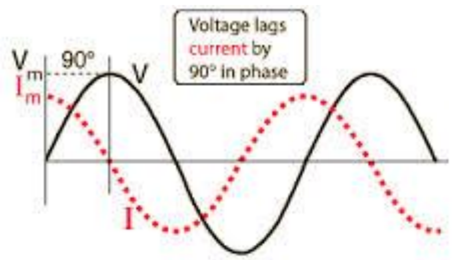
- **<u>Capacitive reactance</u>** is given by the formula:

$$X_C = \frac{1}{2\pi f C}$$

  - where X_C is the capacitive reactance in ohms
  - where f is the frequency in Hertz
  - where C is the capacitance in Farads
  - and the symbol π equals 3.14

- By the above formula, as the frequency or the capacitance value increases, the capacitive reactance decreases.

- As opposed to inductors, AC applied to a capacitor, voltage will lag the current by 90 degrees as shown below:



- **Capacitance**

- **The Standard International Unit for capacitance is the Farad (F)** which is equivalent to one coulomb per volt (or 6.241 x 10^{18} electrons of charge per volt potential)

- Capacitor capacitance values are greater with larger surface area to the plates and/or narrower separation between the plates. Conversely, capacitor values decrease with smaller area to the plates and/or larger separation.

- **Capacitors** also have a specified **working voltage**; exceeding the working voltage may result in the breakdown of the dielectric and failure of the device. Having a wider separation between the capacitor conductors or plates usually contributes to a higher working voltage.

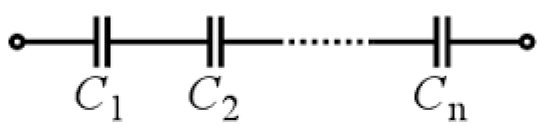
- **Capacitors are widely used** in electronic circuits for **blocking DC while allowing AC to pass.** They are used in **power supplies to smooth and stabilize the output** and **in resonant circuits to tune radios to particular frequencies.**

- Typical values of capacitors in electronic circuits range from 1 pF (10^{-12}F) to many 1000 of uF (10^{-6}F).

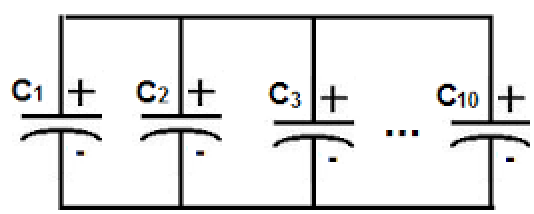
- For Capacitors in Parallel, the total Capacitance is equal to the sum of the capacitance of the individual capacitors. Note this is the **inverse** to the formula for resistors or inductors.

- **Capacitors in <u>Series</u>** follow a more complicated **formula similar to resistors and inductors in <u>parallel</u>**.

- The following formulas apply for Capacitors connected in series and parallel:



In Series



In Parallel

Capacitances

$$C_{series} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \ldots \frac{1}{C_n}}$$

$$C_{parallel} = C_1 + C_2 + \ldots C_n$$

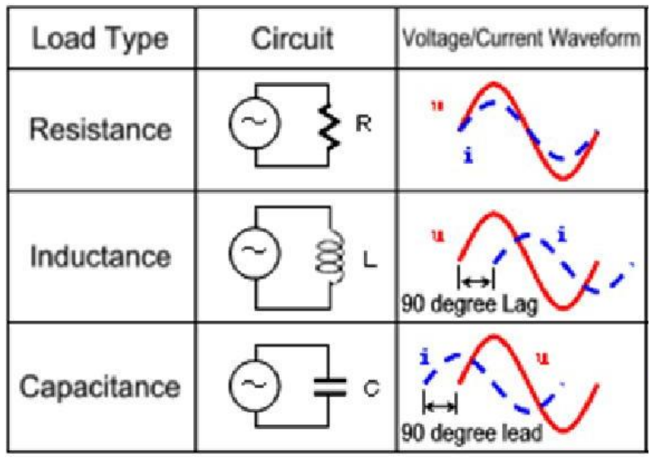
Where,

C = Capacitance in farads

- When two or more equal value capacitors are connected in series, the total capacitance will be simply the value of capacitance of one of the capacitors divided by the number connected in series.

- Expect several questions on the Basic exam that relate to calculating Inductors and Capacitors in Series and Parallel.

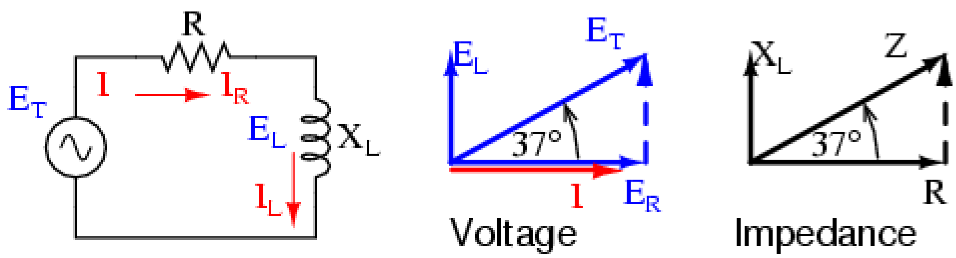
Impedance



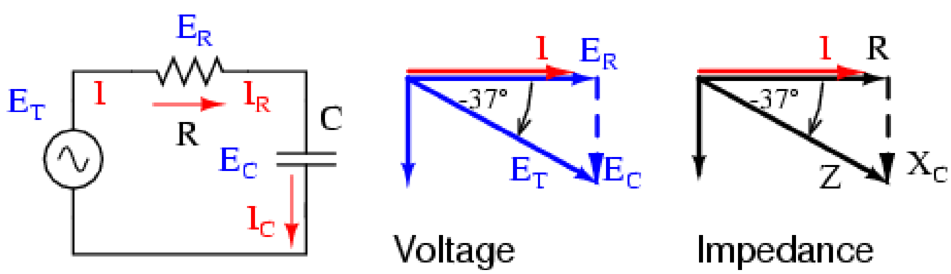
- Note that for AC applied to an **inductor**, the **current lags** the applied **voltage** by one quarter of the AC cycle **or 90 degrees**. With respect to a **capacitor**, **voltage lags current by 90 degrees**. It is because of this phenomena we have the term **Electrical Impedance** which is the measure of the opposition that a circuit presents to a current when an AC voltage is applied. For DC, there is no distinction between impedance and resistance, the latter can be thought of as impedance with zero phase angle since an idea resistor, peak current in a circuit is when there is peak voltage and vice versa.   However, in an AC circuit with inductance (and/or) capacitance, there are two components being magnitude and phase.   From an AC circuit, real power can only be transferred based on the components of voltage and current that overlap constructively in the cycle. **The symbol for impedance is "Z"** and should be written as a complex number with real and imaginary parts. However the overall opposition to a AC current, Impedance, is in the same units as resistance, that is ohms (Ω). The reciprocal of impedance is admittance with the units like conductance, "Siemens".

Vector Representation of Impedance (Z)

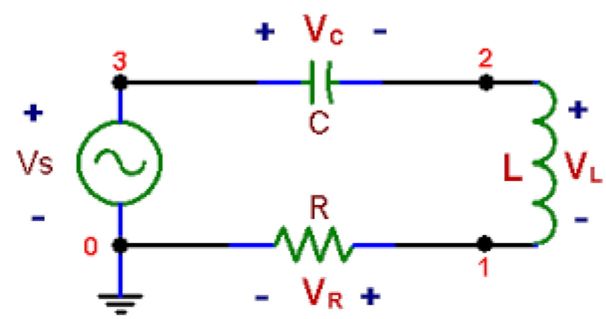
For an Inductor and Resistor in an AC circuit.



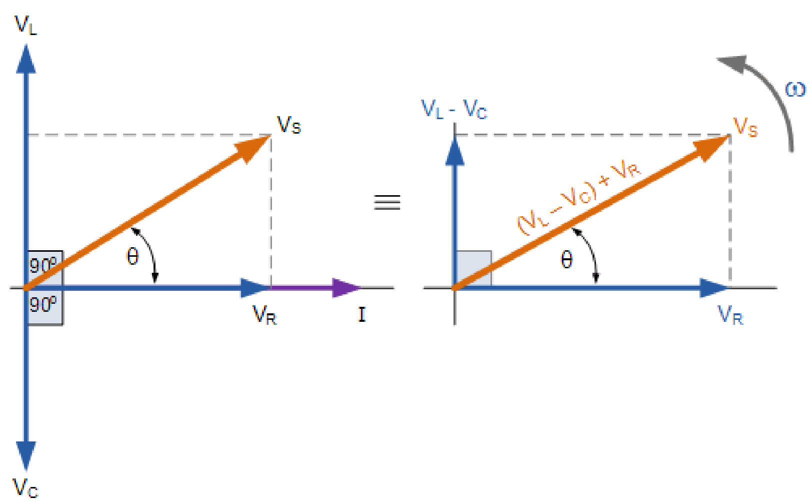
For a Capacitor and Resistor in an AC circuit.



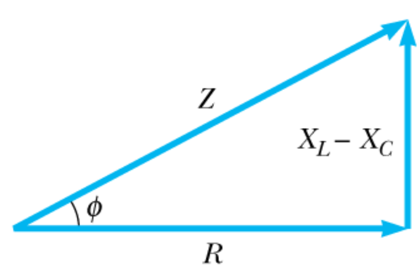
- For both above, the phase angle is dependent on the AC frequency and the values of the inductor or capacitor and resistor in the circuit.



- For the circuit above which is a combination of a capacitor, inductor and resistor (in series), the impedance is based on the combined reactance of the inductor and capacitor that subtract from each over because they are vector opposites.

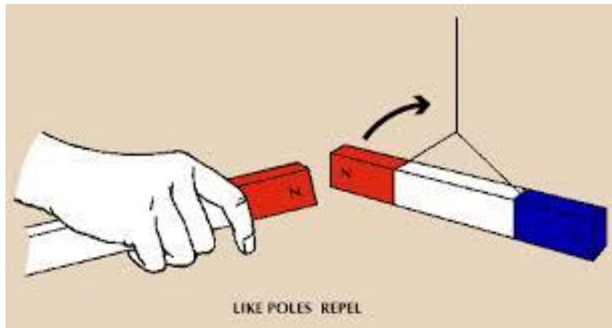


The Impedance Triangle : Knowing R and the combined reactance of (X_L-X_C) then Z can be found using Pythagorean Theorem.



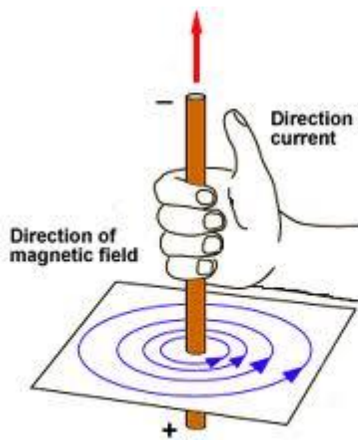
5- 11 Introduction to magnetics and transformers

- An exam question "***A force of repulsion exists between two <u>like</u> magnetic poles.***"

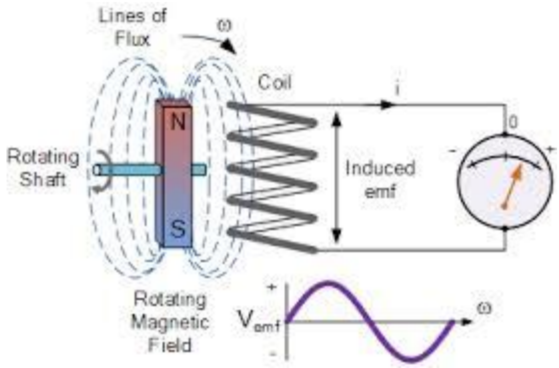


- Unlike poles attract.

- Permanent magnets will be **made of steel** as opposed to other metals like brass, copper or aluminum.



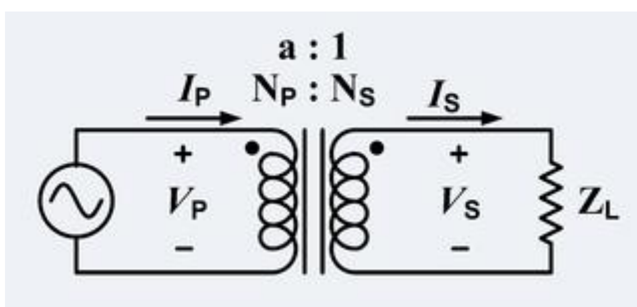
- The strength of the magnetic field around a conductor in air is directly proportional to the current in the conductor.

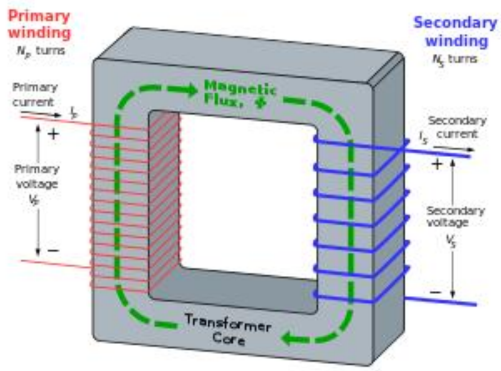


- The voltage induced in a conductor moving in magnetic field (or the magnetic field moving in a stationary conductor) is at maximum when the movement one relative to the other is perpendicular to the lines of magnetic force.

- This principal is a lead-in to the transformer.

- A transformer is an electrical device that transfers energy between two or more circuits through electromagnetic induction and is represented in the following diagrams:





- Transformers can only be used with Alternating Current (AC); they cannot work on Direct Current (DC)

- Transformers use a continuously changing magnetic field created in the iron core by the AC connected to the primary coil to induce an alternating current into the secondary coil, both wound around a common ferromagnetic material which couples with mutual induction.

- Transformers are primarily used to increase or decrease voltage and current from a primary circuit to one or more secondary circuits.

- The voltage output of the transformer on the secondary coil compared to the voltage applied to the input primary coil is directly **proportional to the turns ratio** of primary to secondary coils.

- As an example, if the primary winding of a transformer is 100 turns and the secondary is 10 turns, and if 100 volts AC is applied to the primary winding, the result would be 10 volts AC as an output voltage across the secondary winding. (step-down configuration)

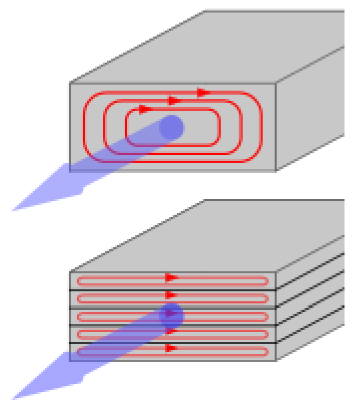
- Conversely, for the same transformer as above, 10 volts AC applied to the secondary coil (now the primary) would result in 100 volts AC output on the primary (now the secondary) winding. (step-up configuration)

- There will likely be several questions on the exam that deal with turns ratio calculations of transformers.

- In all practical transformers, there is energy transfer **losses** from input power applied to output power that can be realized. A well designed transformer will have these losses minimized so that the output power (secondary product of Voltage (V) x Current (I) will almost equal the input power delivered to the primary input (primary product of V x I). Good under loaded transformer design should have efficiency of above 90 %.

- One aspect of efficient transformer design is to make the steel magnetic material using **"laminations"** of sheet steel with each laminate layer insulted from the other with a special varnish. This reduces electrical conduction within the core from what is known as eddy currents. Such **eddy**

currents flowing in the core reduces power transfer by generating heat within the core itself. The other source of power transfer loss is the **ohmic resistance of the winding wire conductors** that again produces heat.

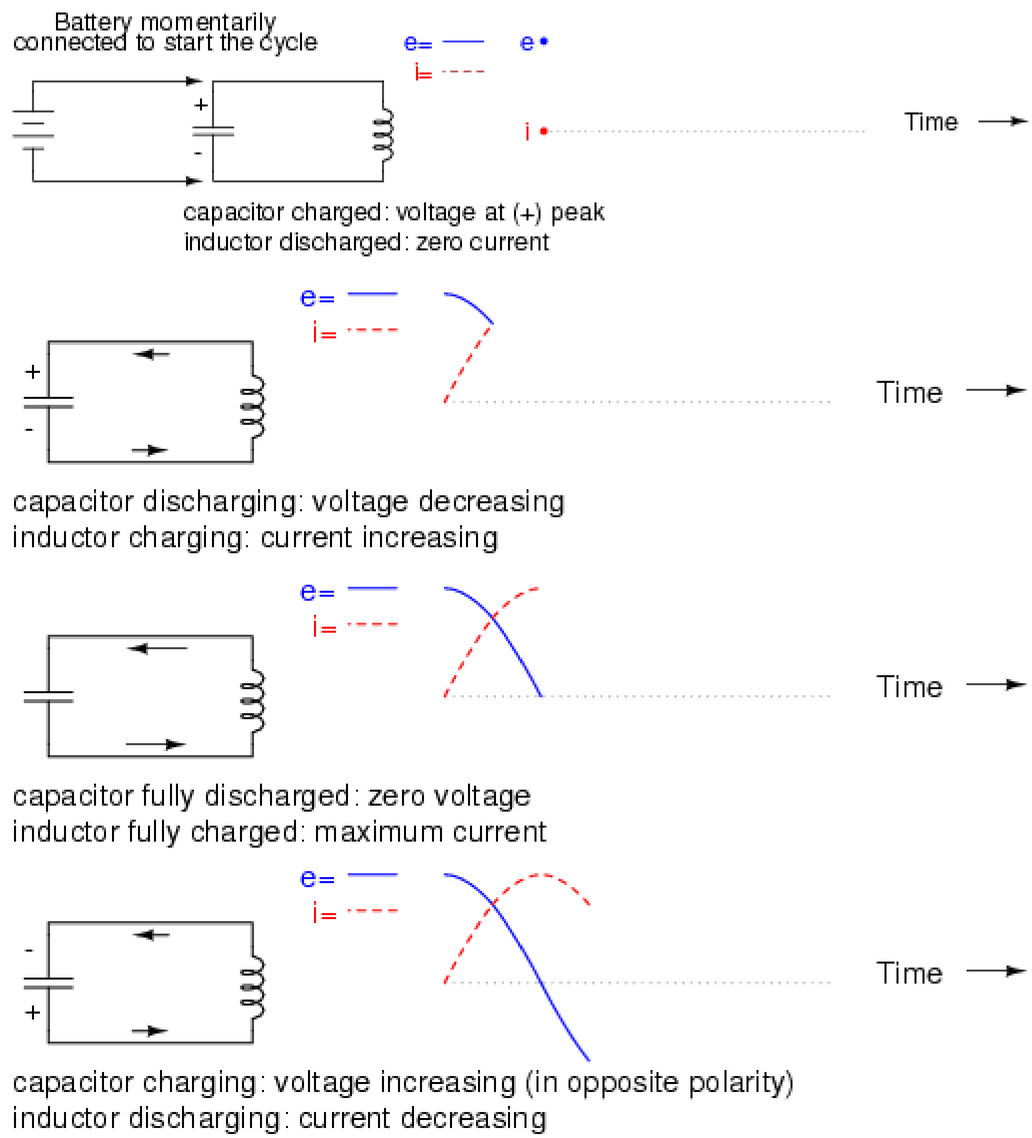


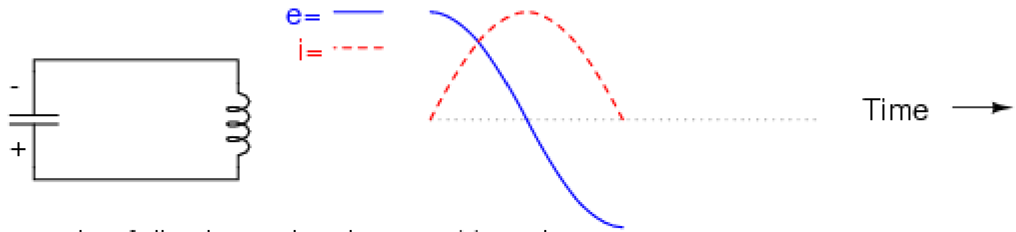
Laminating the core greatly reduces eddy-current losses shown above.

- The current drawn by the secondary load will be reflected as a proportional current drawn in the primary circuit based on the turns ratio of the transformer. However, it should be expected that even with an open circuit of the secondary windings, with **no load connected**, **the current in the primary circuit will not be zero**. Some small amount of current known as the **"magnetizing current"** of the transformer will flow in the primary circuit.

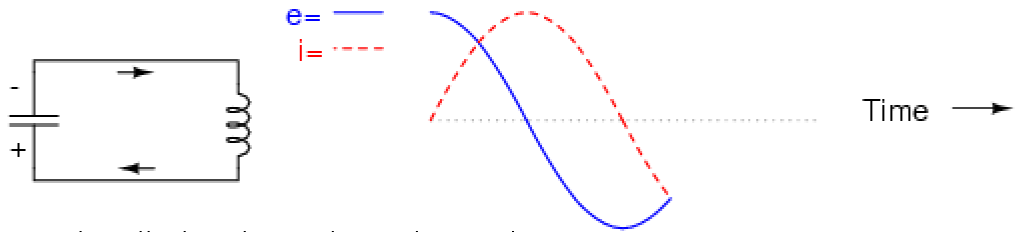
5-12 Introduction to Resonance and Tuned Circuits

- From our discussion of Inductors and Capacitors, we know both have the ability to store electrical energy. If we connect a capacitor and inductor in parallel and momentarily give the circuit a kick with a charge from a battery, we would start the circuit into electronic motion.

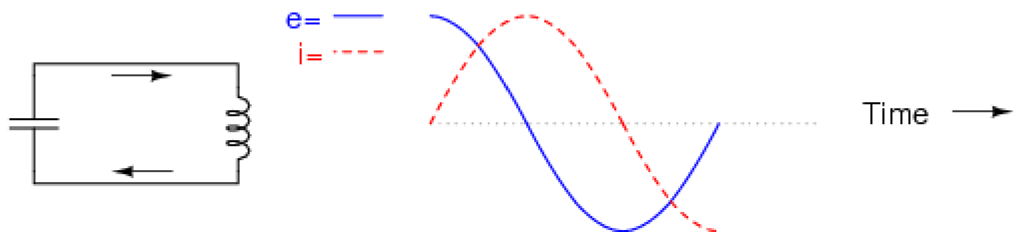




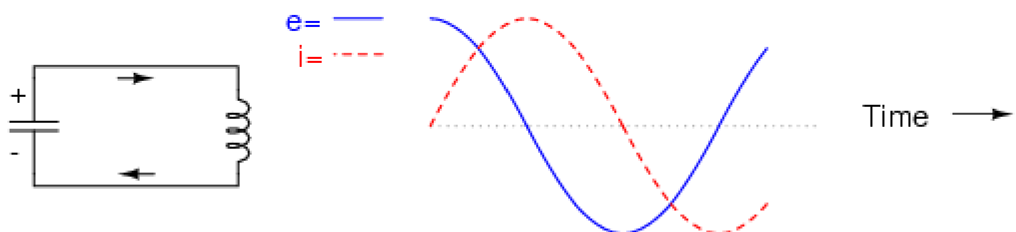
capacitor fully charged: voltage at (-) peak
inductor fully discharged: zero current



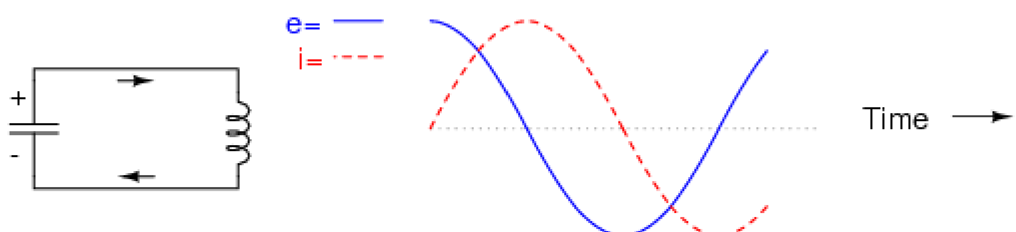
capacitor discharging: voltage decreasing
inductor charging: current increasing



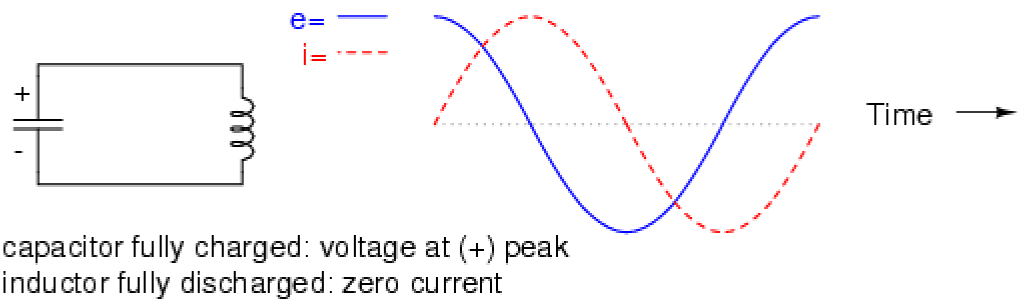
capacitor fully discharged: zero voltage
inductor fully charged: current at (-) peak

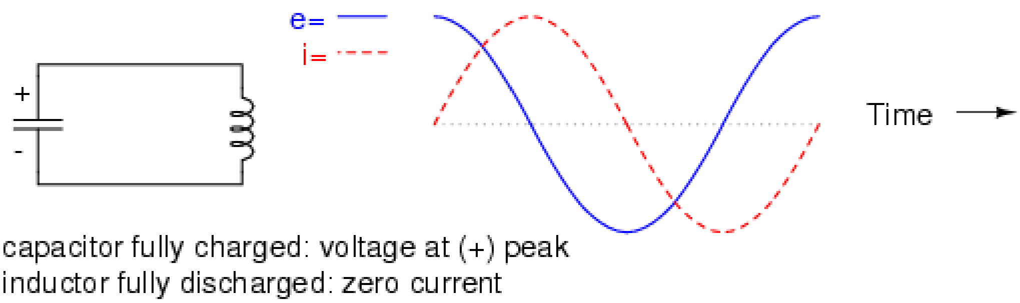


capacitor charging: voltage increasing
inductor discharging: current decreasing



capacitor charging: voltage increasing
inductor discharging: current decreasing





- See: http://en.wikipedia.org/wiki/LC_circuit#mediaviewer/File:Tuned_circuit_animation_3.gif

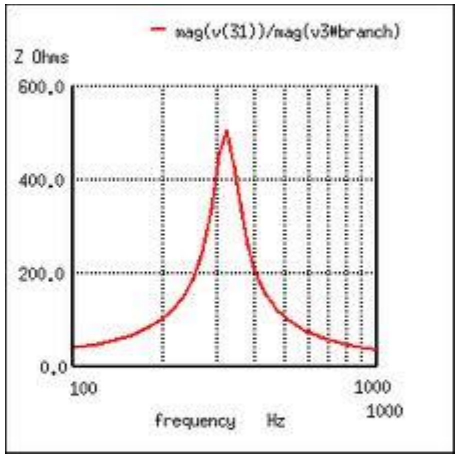
- This oscillation will continue (a very short period to time) with steadily decreasing amplitude due to power losses from stray resistances in the circuit until the process stops altogether.

- The rate of the oscillation or Frequency ***(f)*** will be determined by the amount of inductance (L in Henrys) and capacitance (C in Farads) based on the following formula:

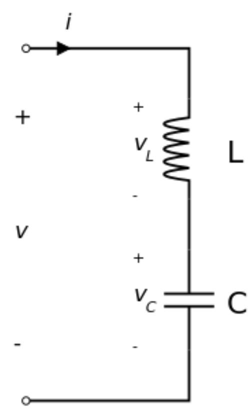
$$f = \frac{1}{2\pi\sqrt{LC}}$$

- The above formula is known as the **Resonant Frequency of an LC circuit**.

- **<u>A parallel LC circuit has a High Impedance</u>** to AC signal applied across it **<u>at its Resonant Frequency</u>** as shown in this diagram:

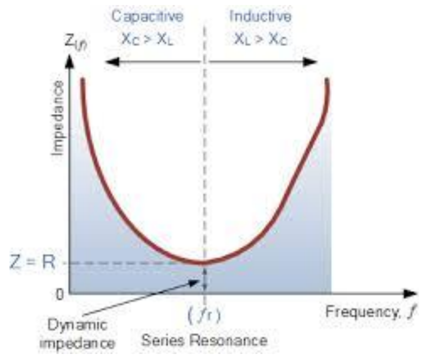


- **<u>Series LC circuit</u>**



- In the above **<u>series LC circuit</u>**, at the **<u>resonant frequency</u>**, the Inductive Reactance X_L will equal the Capacitive Reactance X_c with opposite signs ($X_L = - X_c$) and therefore cancel out leaving nothing but the **low resistance in the circuit components and wiring**. This **<u>low impedance of the series LC circuit is opposite to the high impedance of the resonant parallel LC circuit.</u>**

- The low impedance at the resonant frequency of a Series LC circuit vs Frequency is shown in the following diagram:



- **<u>Adding resistance in an LC circuit</u>** effects the Quality factor (Q) of the circuit but **<u>does not affect the resonant frequency</u>** based on the values of the Inductor or Capacitor.

- Expect questions on the impedance of Series and Parallel Resonant Circuits.

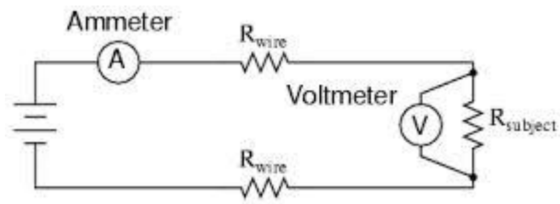
5- 13 <u>Introduction to Meters and Measurements</u>

- A Multimeter usually refers to a meter (Analogue or Digital) that is designed to measure AC and DC Voltages, AC and DC Current, and Resistance.

- When **measuring voltage**, the volt meter is **applied in parallel** with the circuit or component under test.

- And when **measuring current**, a **Ammeter is connected in Series** with the circuit or component under test.

- The following diagram shows the appropriate connection of both a voltmeter and ammeter in the same circuit.



$$R_{subject} = \frac{\text{Voltmeter indication}}{\text{Ammeter indication}}$$