MODULE 2

Amateur Radio Basic Course Preparation

Getting Down to Basics

Chapter 2

References

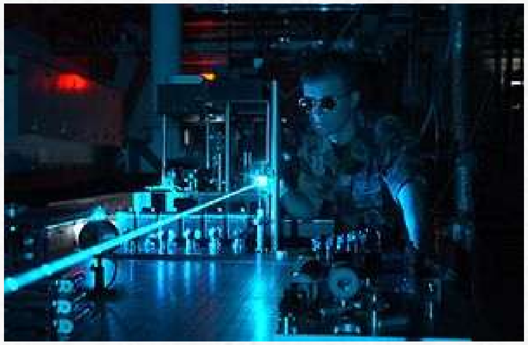
- *Canadian Amateur Radio Basic Qualification Study Guide* (2009), Chapter 2, 3 and 4
- RIC-7: Basic Qualification Question Bank for Amateur Radio Operator Certificate Examinations Issue 3, April 2007 http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01900.html

Outline

- Introduction
- Electrical Theory
  - Atomic Theory
  - Current and Voltage
  - Conductors and Insulators
  - Resistance and Resistors
  - Conductance and Insulators
  - Magnets
  - Direct Current, Sources and Batteries
  - Circuit and Schematic Diagrams
  - Alternating Current, AC Generators, Terminology
  - AC v. DC
- Conclusion

Introduction

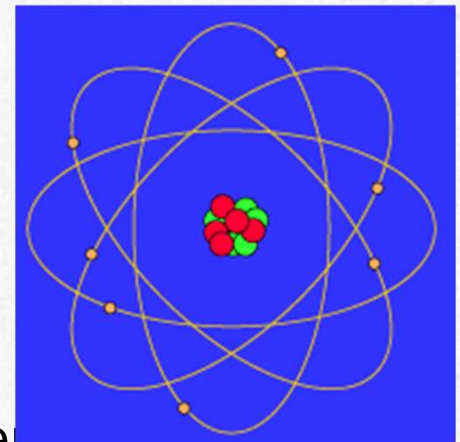
- What is physics?
- Attempt to understand nature
  - Classical mechanics
  - Acoustics
  - Optics
  - Thermodynamics
  - Electromagnetism
  - Modern physics



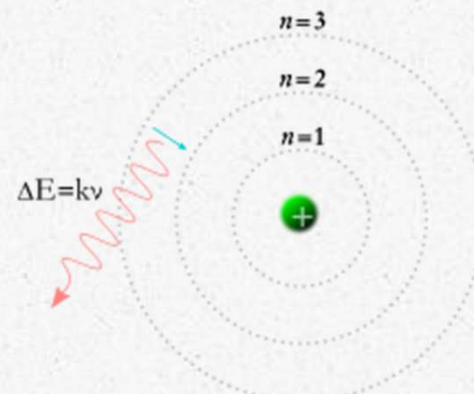
$$\frac{\partial^2 u}{\partial t^2} = c(u)^2 \nabla^2 u$$

$$i\hbar \frac{\partial}{\partial t} \Psi(\mathbf{r}, t) = \hat{H} \Psi(\mathbf{r}, t)$$

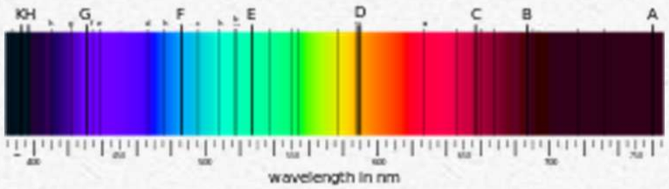
Atomic Theory

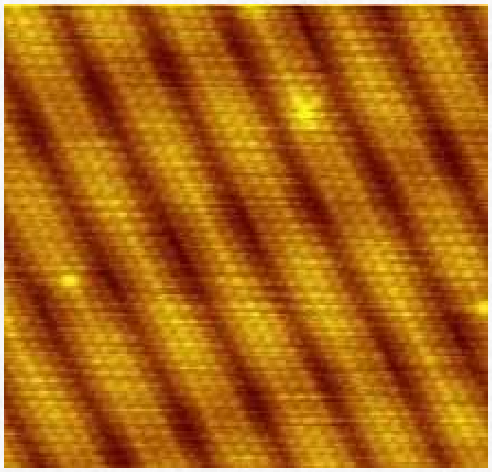


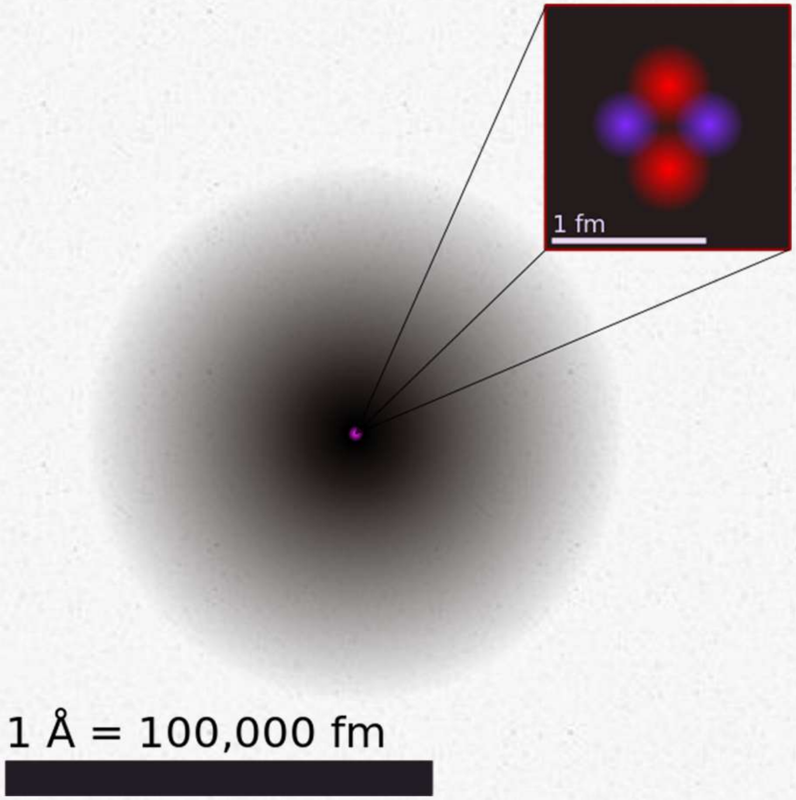
- Atom – basic unit of matter
  - Nucleus
    - Neutrons (neutral)
    - Protons (+ 1.602 x10^{18} Coulombs)
    - Atomic Number
  - Electrons (- 1.602 x10^{18}C)
- Electric charges – strongest force in universe
  - electrostatic attraction (+ - OR - +)
  - electrostatic repulsion (++ OR - -)
- Ionization
  - valence electrons
  - shells, energy levels



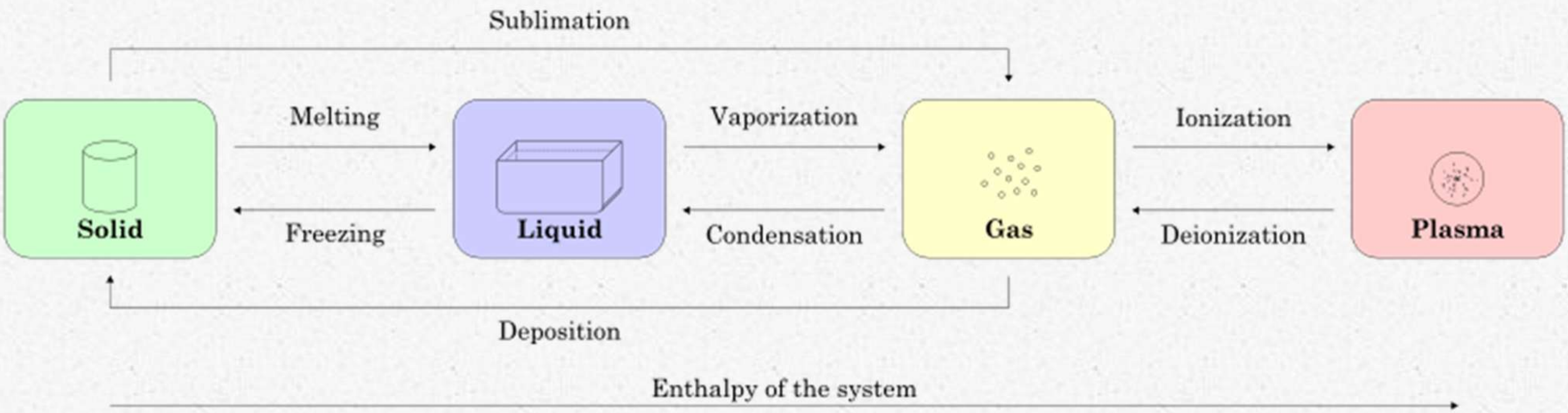
Helium







States of Matter (4)



Periodic Table

Group → ↓ Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo

Lanthanides	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Current

$$I = \frac{\mathrm{d}Q}{\mathrm{d}t}.$$

- Flow of electric charge through a medium
- Analogy to flow of water through a pipe/river
- Rate
  - 1 C/s = 1 Ampere (A)
  - ammeter
  - magnetic field
  - 0.001 A = 1 mA
- Current Flow
  - electron current - to +
  - conventional current – to + but hole goes + to –
    - (transistor theory)

Voltage

- What makes a river flow? Incline – gravity – potential energy
- What makes current flow? Electric potential energy (E) or voltage (V) or electromotive force (EMF)
  - the work that would have been done, per unit charge, against a static electric field to move the charge between two points
- Voltmeter
- mV, μV

Conductors and Resistors

- Conductors
  - metals - valence electrons – Cu, Ag, Al
  - plasma
- Many things conduct but they conduct inefficiently
  - Resistor
  - Opposition to the flow of electrons is called resistance
  - Like rocks in a stream
  - Unit of measurement is the Ohm (Ω)
  - Ohmmeter
  - k Ω, M Ω

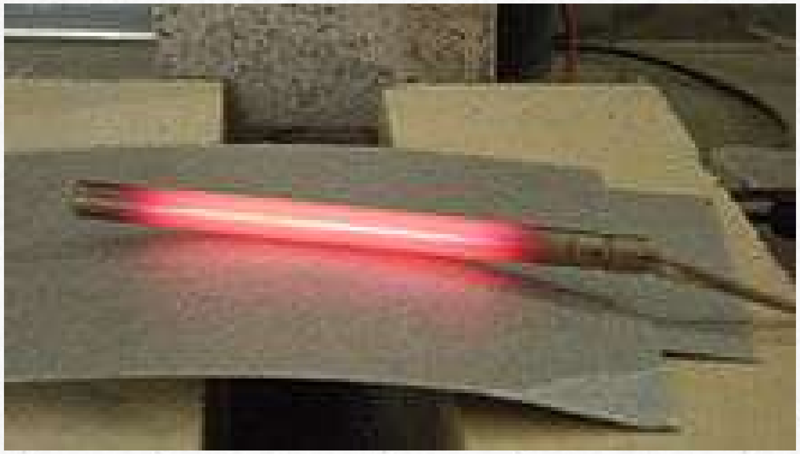
Question

- If lightning is electrical and air is a poor conductor, why does lightning exist?

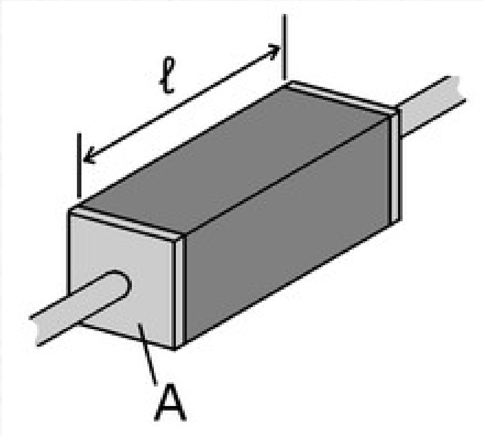
Resistors

- Opposition to flow of electrons is resistance Ω
- Ohm is the resistance of a conductor that will allow exactly 1 A of current to flow in the conductor when one volt is applied to the conductor

Resistance



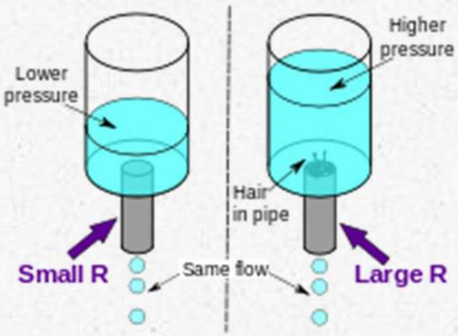
$$R = \rho \frac{\ell}{A},$$



Resistance

- Specific Resistance (material)
- R varies directly with length (R ↑ as L↑)
- R varies indirectly with diameter (R ↑ as D↓)
  - 14 AWG carries 15A, D=1.63 mm, R=2.52Ω/1000 ft
  - 28 AWG low current, D=0.33 mm, R=64.9Ω/1000 ft
- Varies depending on material of conductor
  - R ↑ as T↑ - positive temperature coefficient rating (metals)
  - R ↑ as T↓ - negative temperature coefficient rating (semiconductors)

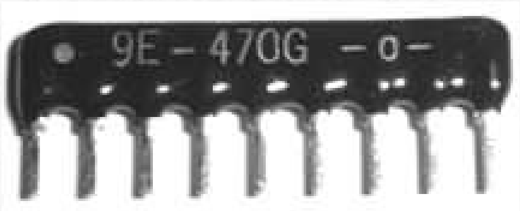
Resistor



- Used to control the flow of current in a circuit
- Tends to dissipate power as heat
- rated in Watts (W)
  - What happens if rated power < actual power?

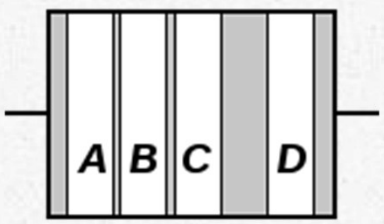
Resistors

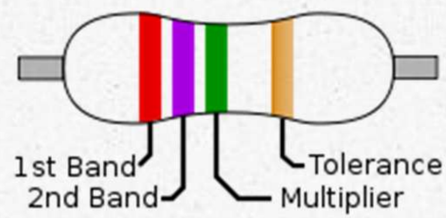
- Fixed – value is of resistance is constant
- Tapped – along length of resister there are taps or connections effectively dividing it into various resistances
- Variable – Turning shaft or moving slide




Resistors

- Composition
  - composition – thin carbon film over ceramic core (variable)
  - wire-wound – wire wound around ceramic core (variable)
  - colour codes or ohmmeter





Resistors

Color	Significant figures	Multiplier	Tolerance		Temp. Coefficient (ppm/K)	
Brown	1	$\times 10^{1}$	±1%	F	100	S
Red	2	$\times 10^{2}$	±2%	G	50	R
Orange	3	$\times 10^{3}$	–		15	P
Yellow	4	$\times 10^{4}$	(±5%)	–	25	Q
Green	5	$\times 10^{5}$	±0.5%	D	20	Z
Blue	6	$\times 10^{6}$	±0.25%	C	10	Z
Violet	7	$\times 10^{7}$	±0.1%	B	5	M
Gray	8	$\times 10^{8}$	±0.05% (±10%)	A	1	K
White	9	$\times 10^{9}$	–		–	
Gold	–	$\times 10^{-1}$	±5%	J	–	
Silver	–	$\times 10^{-2}$	±10%	K	–	
None	–	–	±20%	M	–	

22×10^{4}= 2.2 kΩ +/- 200 Ω
½ W

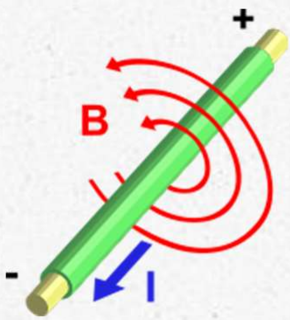
Better Be Ready or Your Great Big Venture Goes West

Conductance

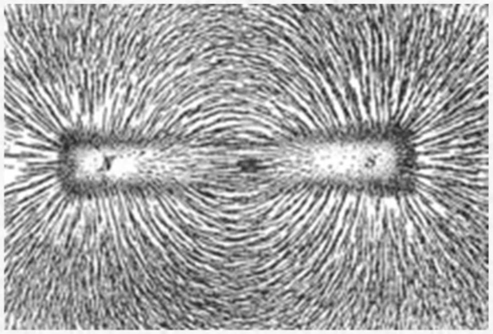
- Reciprocal of resistance i.e. $1/R=G$
- Measured in siemens
- If conductance (G) is high then resistance (R) is low
- If conductance (G) is low then resistance (R) is high
- $10\Omega = 1/10\ \Omega = 0.1\ S$

Insulators

- Insulators have very low conductance – no flow
- Glass, ceramic or plastic



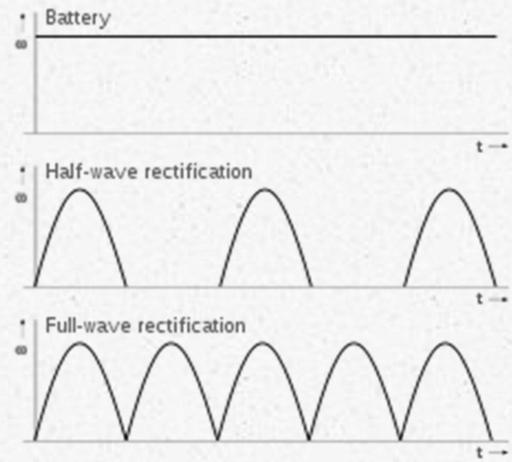
Magnets



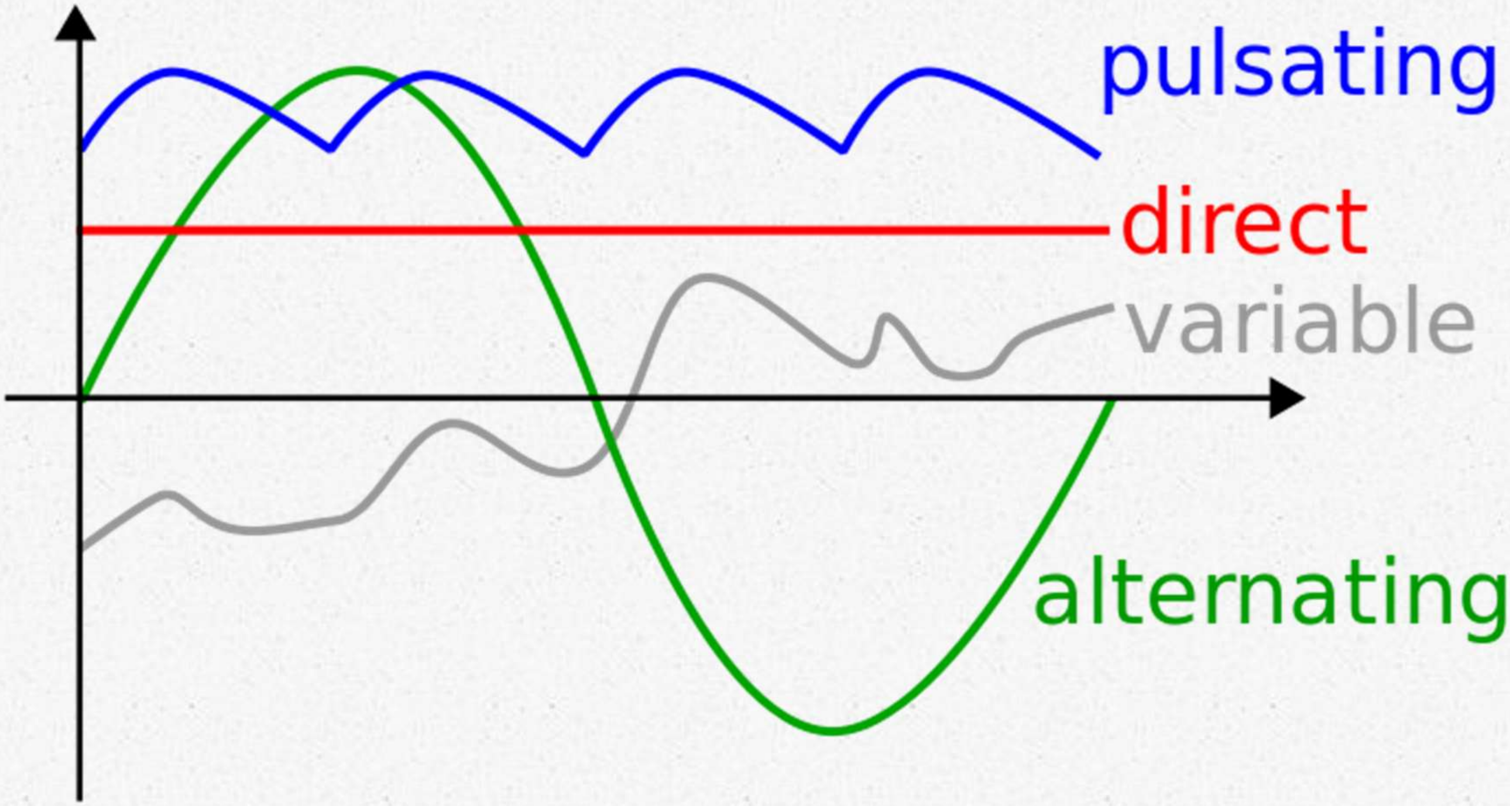
- magnet – magnetic field – poles – horseshoe magnet
- electromagnetism
- moving a conductor through a magnetic field causes an electric current to flow (generator)
- an electric current flowing through a magnetic field causes movement (motor)
- permanent magnets and temporary magnets (electromagnet)

Direct Current (DC)

- Current flows in one direction only
- Sources
  - friction (static)
  - heat
  - pressure (piezoelectric)
  - magnetism
  - photoelectricity (solar panels)
  - chemical action (cells and batteries)

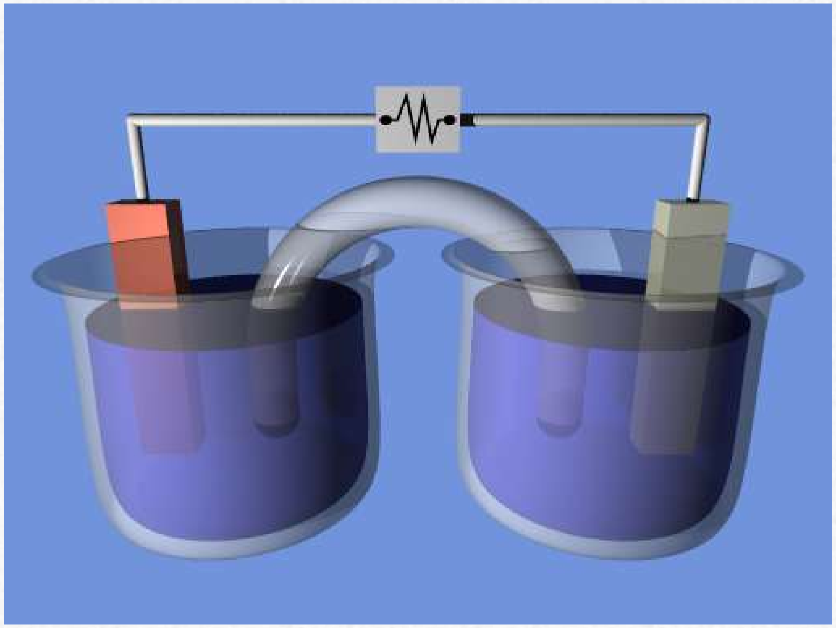


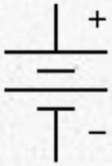
Direct Current



Cells and Batteries

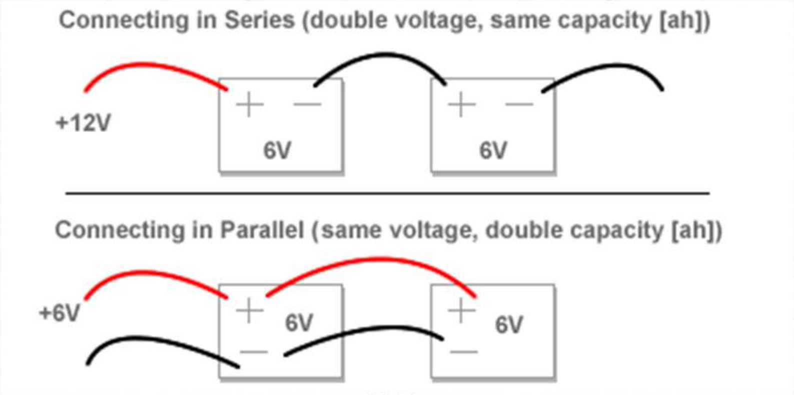
- electrochemical cell
- electrodes, electrolyte





Cells and Batteries

- Series (V) and Parallel (I)
- Primary cells and batteries
- Secondary cells and batteries (rechargeable, storage cells or storage batteries)
  - NiCd shorts…
- Shelf life
- Internal resistance
- Emergy capacity (Ah)



$$I = \frac{V}{R} \quad \text{or} \quad V = IR \quad \text{or} \quad R = \frac{V}{I}.$$

Types of Batteries

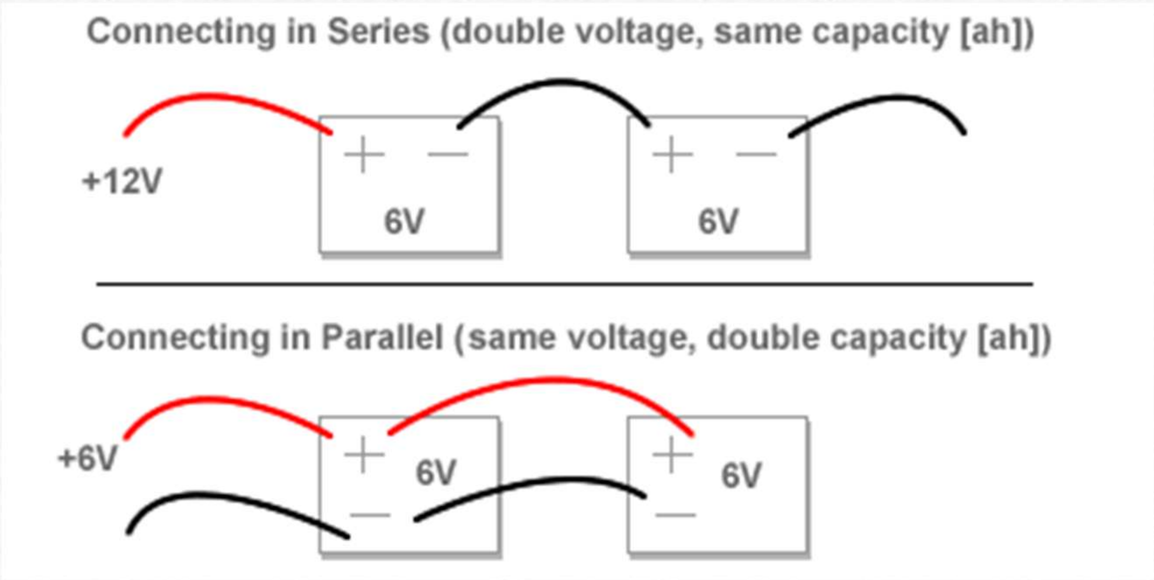
- Carbon Zinc
- Alkaline
- Mercury

Toxicity

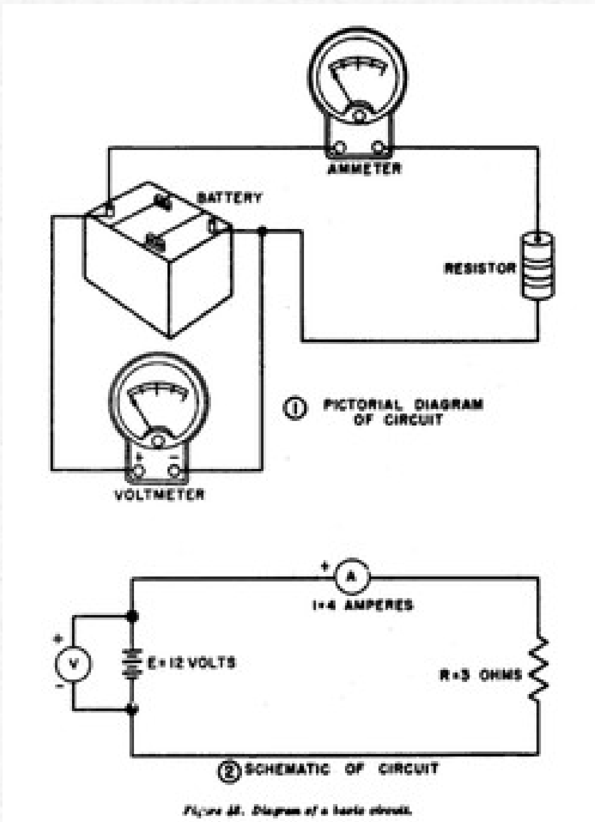
- Nickel Cadmium – each cell 1.25V but never discharge below 1V
- Lead Acid
- Nickel Metal Hydride
- Lithium (CPU clock battery)

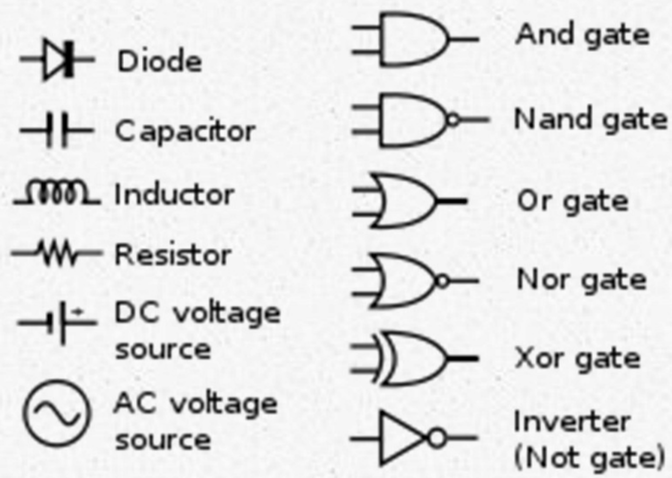
Batteries

- Cells in series → $V = \sum V_i, but\ I\ is\ constant$
- Cells in parallel→ $V = V, but\ I\ is\ doubled$



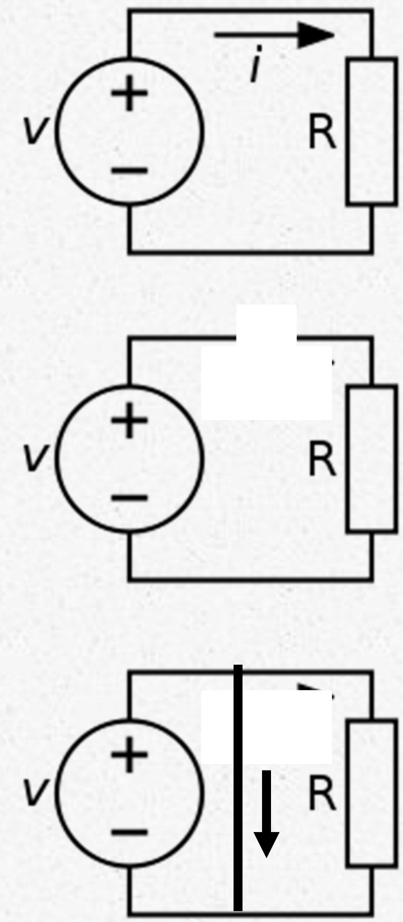
Circuit Diagrams





Circuits

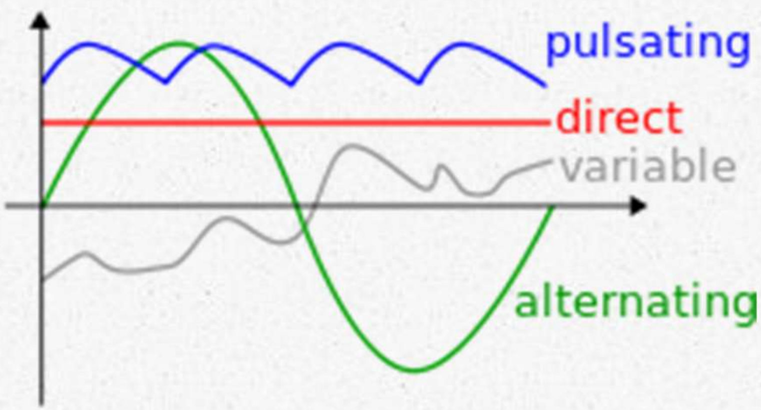
- Closed circuit
- Open circuit
- short circuit
- Appendix 3

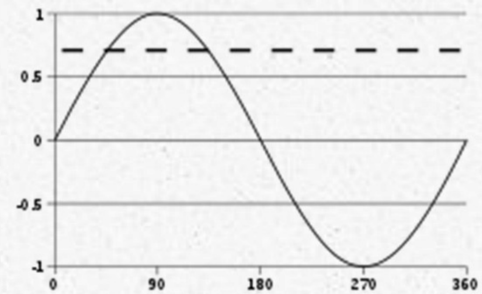


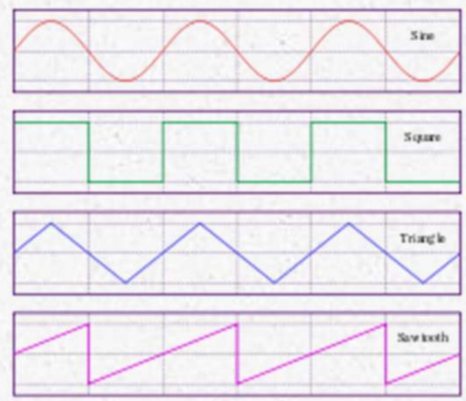
Alternating Current

- AC flows in one direction and then the other with a reversal in the direction of flow or polarity taking place at regular intervals
- Number of complete alterations per second is known as frequency
- In Canada most homes have complete alterations 60 times per second or more correctly 60 Hz (or cycles)
- One could reverse connections of a battery at regular intervals in order to produce AC

AC Current



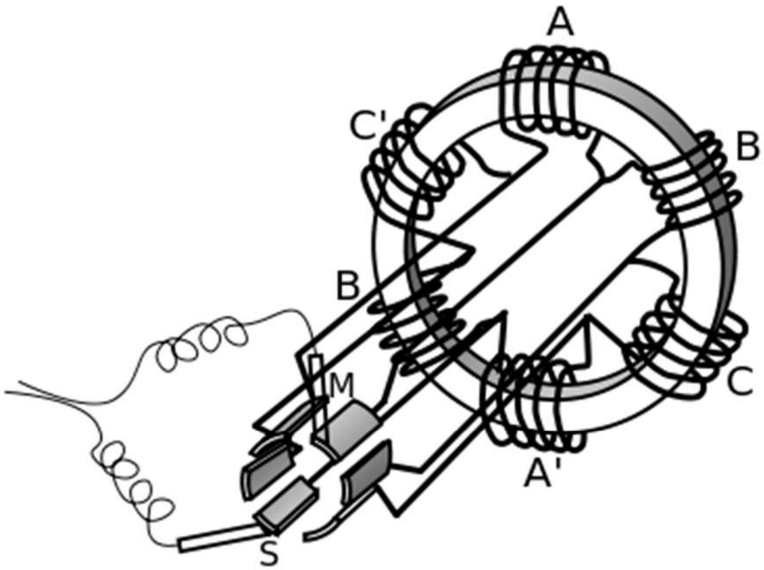


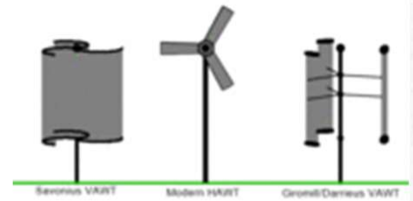


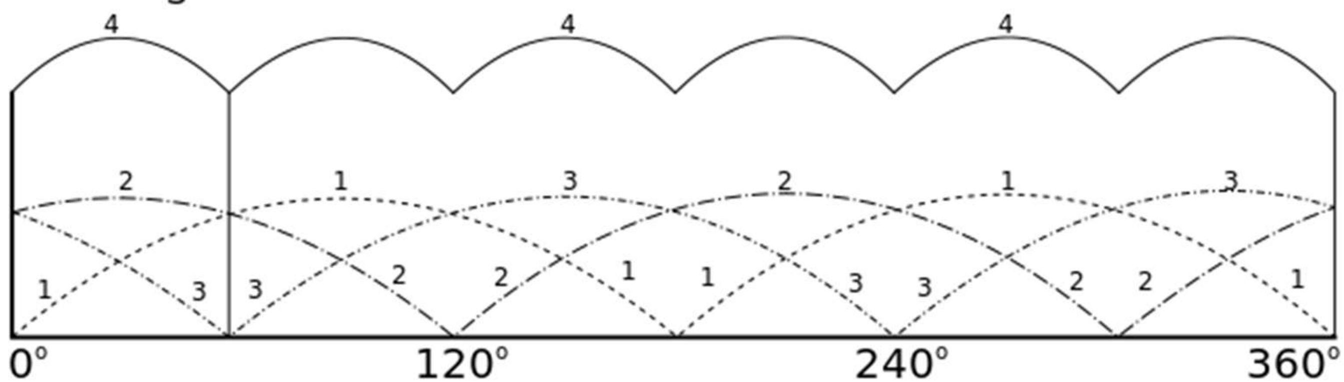
What if current is a sinusoid and it oscillates between 5V and 2V? Is it still AC?

Elementary AC Generator

- car alternator
- loops of wire around a soft iron core called the armature
- When wire moves in a magnetic field current flows through wire
- generator has loops of wires wound around a soft iron core called the armature
- Armature is spun through magnetic field (permanent or temporary magnet)
- Orientation to the field goes through a 360 degree cycle and that is one period of the sinusoid


A
B'
C'
B
M
C
A'
S

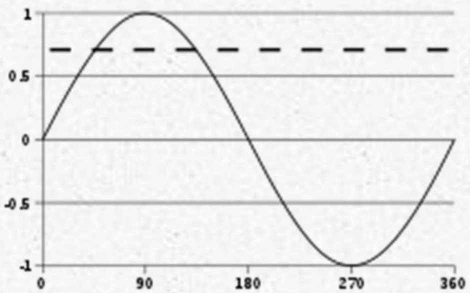

Savonius VAWT
Modern HAWT


4
4
4
2
1
3
2
1
3
1
3
2
2
1
1
3
3
2
2
1
0°
120°
240°
360°

AC and DC Compared

- DC has a constant voltage level but AC varies
- For AC voltage to have same effect (i.e. contain same energy as DC), its peak value must be higher than the DC voltage.
- What we do is average the value of the AC wave.

RMS – Root Mean Square



$$V = a \times \sin(2\pi f t) + V_{DC}$$

$$V_{rms} = \frac{a}{\sqrt{2}}$$

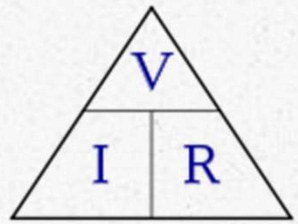
In mathematics, the root mean square (abbreviated RMS or rms), also known as the quadratic mean, is a statistical measure of the magnitude of a varying quantity. It is especially useful when variations are positive and negative, e.g., sinusoids. RMS is used in various fields, including electrical engineering.

-peaks of the wave
-negative peaks
-peak to peak voltage
-Voltage and current are in phase
V=IR

Ohm’s Law and Power: Current in Action

Chapter 2

Ohm’s Law



$$I = \frac{V}{R} \quad \text{or} \quad V = IR \quad \text{or} \quad R = \frac{V}{I}.$$

- convert base units of V, I or R to standard or base units (V, A or Ω
- make sure you use correct units

Example

- We have a battery of 12 V, an open switch and a resistor of 25Ω. What is the current in the circuit when the switch is open? And closed?
  - no current when switch is open
  - when circuit is closed
    - $I = \frac{V}{R} = \frac{12V}{25\Omega} = 0.48A = \mathbf{480}\boldsymbol{mA}$

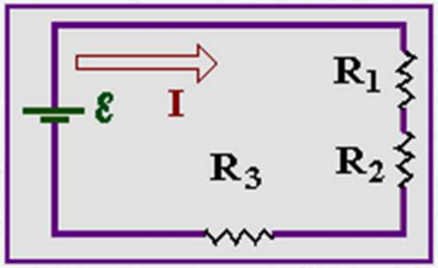
$$I = \frac{V}{R} \quad \text{or} \quad V = IR \quad \text{or} \quad R = \frac{V}{I}.$$

Calculations

- If you are given quantities in non-base units, make sure you convert to base units
- e.g. Suppose in previous problem the resistance given was 0.025kΩ
- Failure to do this will put your calculations out by magnitude 10^x

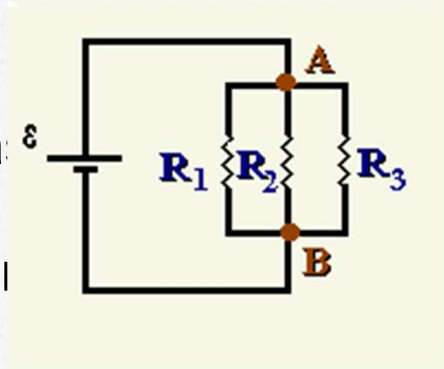
Resistors in Series

- if resistors are placed in series then the sum of the resistances is the overall resistance
- $R_T = R_1 + R_2 + \ldots$
- Recall that V=IR
- Current going through the circuit is the same everywhere
- Voltage is the voltage across R_1 plus the voltage across R_2



Resistors in Parallel

- resistors in parallel have nodes
- the current splits up
- most current takes the path of least resistance
- $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$
- V=IR
- voltage across each resistor is the same a
voltage
- total current in circuit is the sum of the cur
flowing in each branch
- total resistance is always less than any individual resistance



Example

- We have R1=300 ohms, R2=200 ohms and R3=100 ohms.
  - What is equivalent resistance of R1 and R2?
  - $\frac{1}{R_{eq}} = \frac{1}{300\Omega} + \frac{1}{200\Omega} + \frac{1}{100\Omega} = \frac{2+3+6}{600\Omega} = \frac{11}{600\Omega}$
  - $R_{eq} = \frac{600\Omega}{11} = 54.5\Omega$
  - Note it is less than 100 ohms
  - Need to know how to work with fractions

Power

- Energy is the ability to do work
- Energy can be stored in a system
- e.g. stretched spring/dam – potential energy
- battery is a storage device for electric potential energy
- when electrons are moved against resistance, work is done $W = Fd.$
- rate of work that is done is called **power**

Power

$$I = \frac{V}{R} \quad \text{or} \quad V = IR \quad \text{or} \quad R = \frac{V}{I}.$$

$$P = V \times I = \frac{V^2}{R} = I^2 \times R$$

- basic unit is the watt or W
- power formulas derived from Ohm's law

Example

- Calculate power expended by a lamp in a circuit that is powered by a 12V battery and that has a current of 5A.
- $P = V \times I = 12V \times 5A = 60W$
- Suppose the light bulb in a home lamp has a resistance 360 ohms (the home voltage is 120V). What is the power consumed by the bulb?
- $P = \frac{120^2 V}{360\Omega} = 40W$

Practice

- Practice sample problems using the Industry Canada exam generator software, RIC 7 or the problems handed out (based on RIC 7).

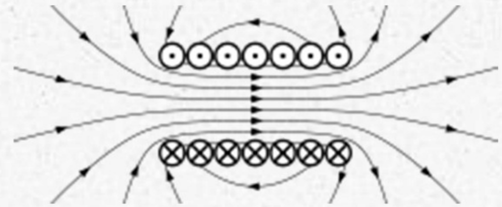
Inductors and Capacitors

Chapter 4

Inductance

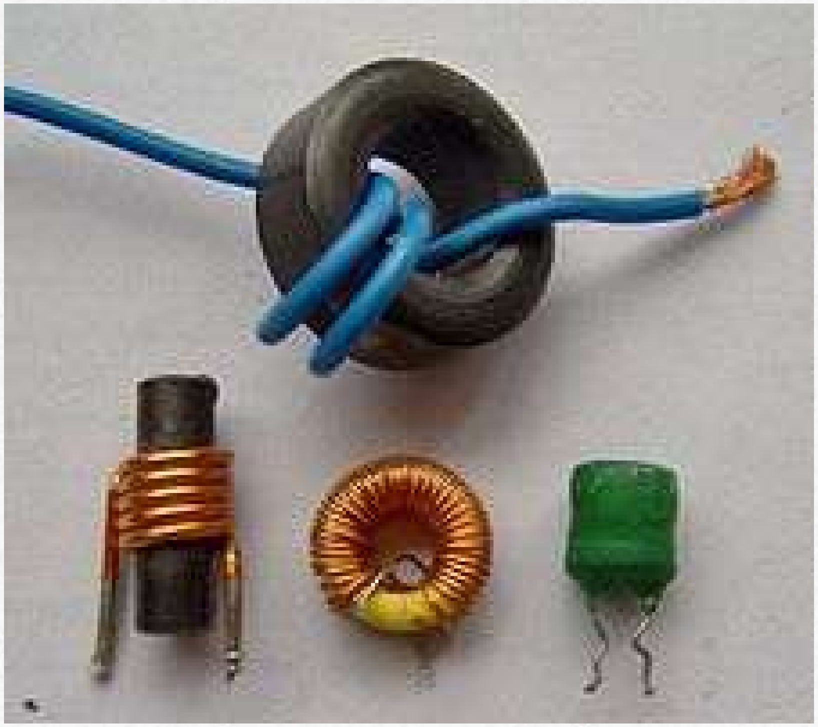
- A straight conductor that carries a current will produce a magnetic field around the conductor in a direction orthogonal to the current flow (left hand rule)
- If the conductor is wound into a spiral or coil the magnetic field is much stronger since the field lines in each turn are all in the same direction and added together.
- A core of magnetic material inserted into the coil can enhance the magnetic field yet again
- A coil with large length and comparatively small diameter is called a solenoid coil

Inductors



- When the circuit is closed and current flows, it takes time for the magnetic field to be established and so the coil limits the rate of increase of current to its maximum
- When the circuit is opened and current stops, the current returned or induced in the conductor is opposite in direction
- The coil is called an inductor
- Very important

Inductors



Inductors

- Magnetic field of inductor
  - proportional to current strength
  - construction of coil (turns, length and diameter)
  - permeability of the core
- A solenoid with an iron core is an electromagnet
- Changing current – AC with inductors is of interest

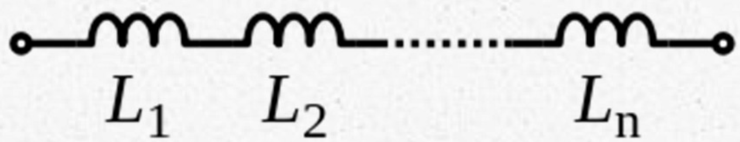
Inductors

- electronic device that makes use of energy stored in a magnetic field
- inductance – opposes any change in current value
- comparable to a flywheel (choke)
- adjustable inductors – moveable ferrite core
- multiple windings – pies
- when magnetic field collapses voltage produced
  - magnitude depends on rate of collapse
  - voltage induced acts in manner to oppose change that caused it – back EMF or counter EMF

Inductors

- Henry (H) and symbol for inductance is L
- Because AC changes the magnetic field will grow and then collapses – self inductance
- Changing number of turns
  - roller inductor or rotary inductor
  - tapping coil at different points along coil
  - installing a shorting switch to short out sections of coil when lower inductance needed
- changing permeability of the core (PTO – permeability tuned oscillator)

Inductors in Series



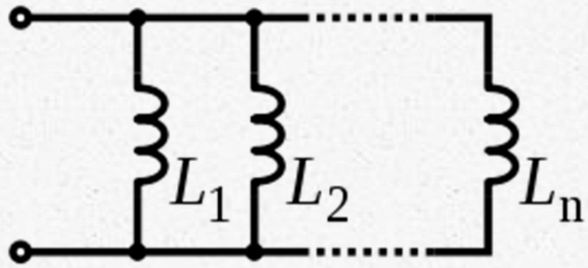
$$L_{eq} = L_1 + L_2 + \dots + L_n$$

Suppose we have two inductors with 2 H and 3 H

$$L_{eq} = 2H + 3H = 5H$$

Just like resistors in series

Inductors in Parallel



$$\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} + \cdots + \frac{1}{L_n}$$

Suppose we have three inductors with 3 H and 6 H and 9 H

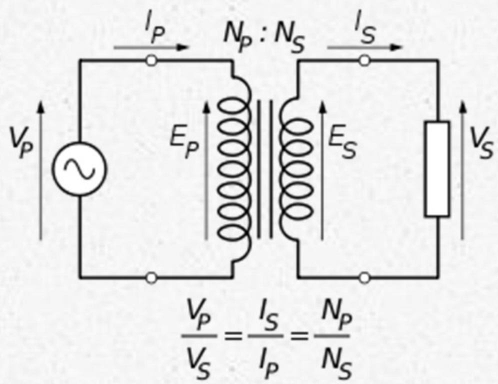
$$\frac{1}{L_{eq}} = \frac{1}{3H} + \frac{1}{6H} + \frac{1}{9H} = \frac{54 + 27 + 18}{162H} = \frac{99}{162H}$$

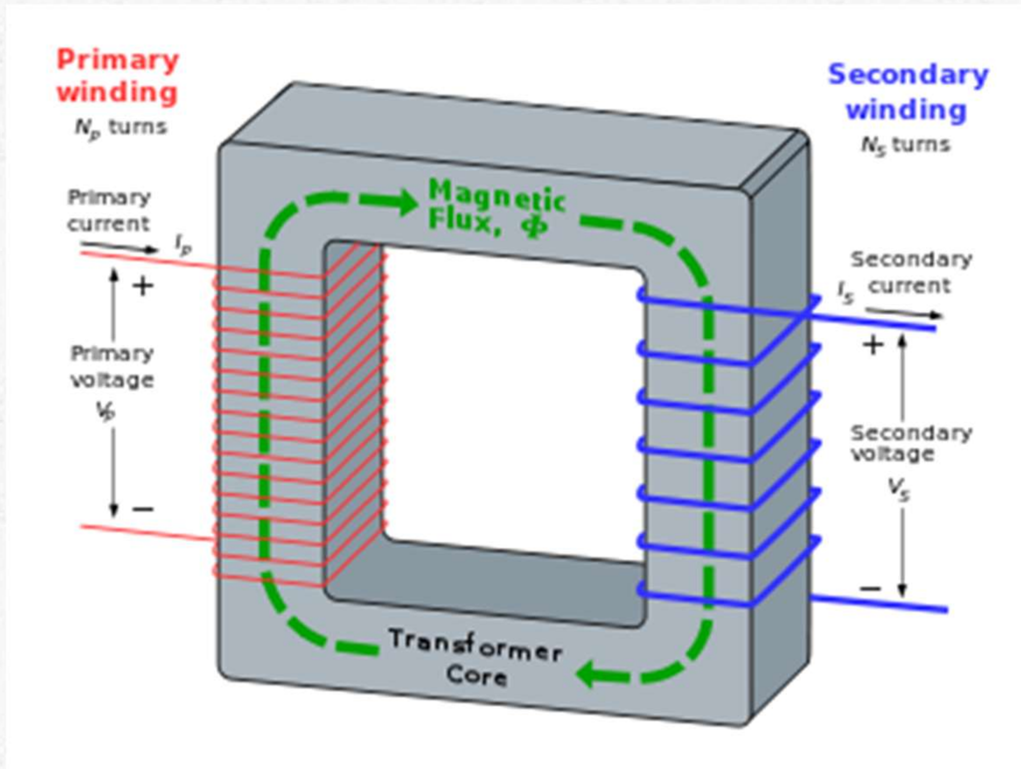
$$L_{eq} = \frac{162H}{99} = 1.64\ H$$

Transformers

- two coils sharing same magnetic field are magnetically coupled
- changing in current in one inductor induces a current in the other inductor – mutual inductance
- primary
- secondary (opposite direction for current
- Voltage is proportional to relative number of turns (windings)

Transformers





$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}.$$

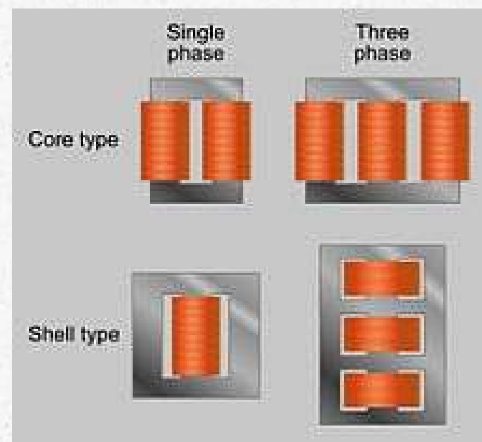
V=IR

This transformer is a "step down" transformer. Why?
What if we change the secondary to the primary. "Step up"?
What if the no. of turns is equal? One to one transformer.

Transformers

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}.$$

- An AC voltage of 150 VAC is applied to primary of a step up transformer whose turns ratio is 2 to 5. 120 turns in primary. Determine secondary voltage and no. turns in secondary.
- $\frac{V_S}{V_P} = \frac{N_S}{N_P} \rightarrow \frac{V_S}{150V} = \frac{5}{2} \rightarrow V_S = 375V$
- $\frac{375V}{150V} = \frac{N_S}{120\ turns} \rightarrow N_s$=300 turns



Transformers

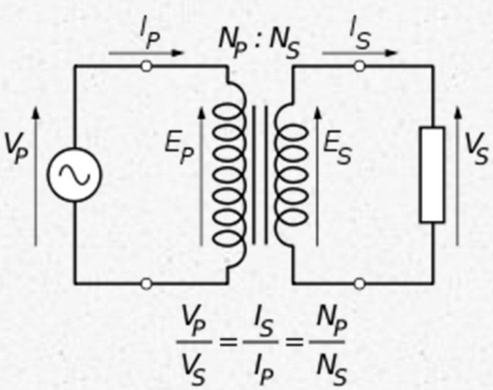
- tight and loose couplings
- if no load attached to secondary, no current induced but current still flows in primary – magnetizing current
- applications in AC circuits
  - isolating one circuit from another electrically (but not magnetically) – one to one transformers
  - raising or lowering voltages
  - matching impedances (baluns)

Transformers

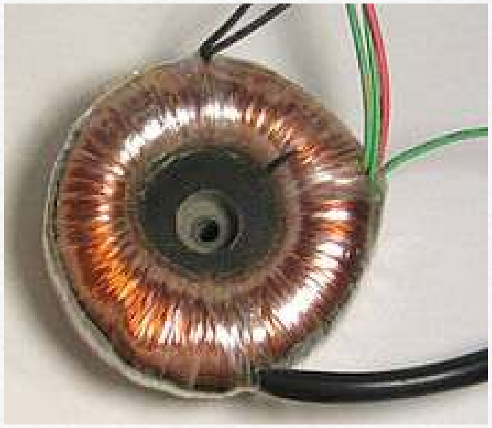
- electric machines not 100% efficient
- losses
  - eddy currents – core losses/iron losses – use of laminations
  - resistance in windings – copper loss
  - magnetic leakage
  - hysteresis – magnetization of the core

Transformers

- P=IV
- P in primary = P in secondary
- Step up transformer increases voltage but it decreases current



$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}.$$

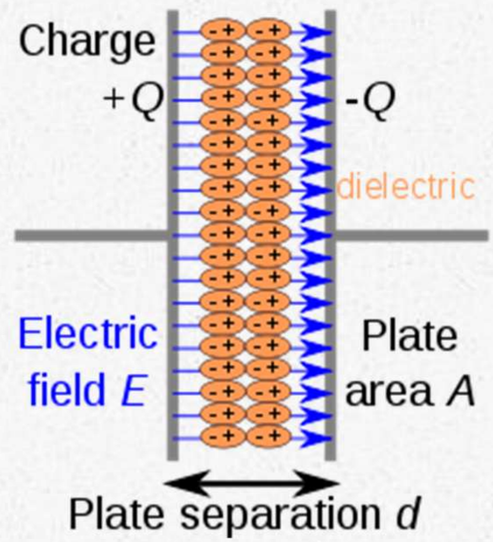


Transformers

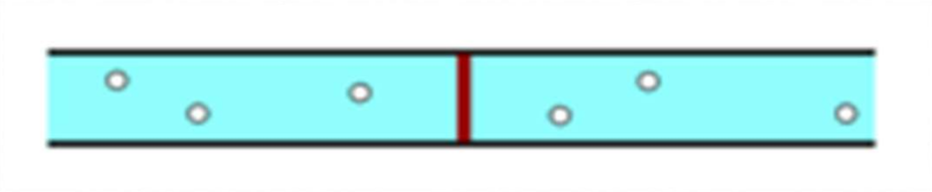
- autotransformer
- In an autotransformer portions of the same winding act as both the primary and secondary. The winding has at least three taps where electrical connections are made. An autotransformer can be smaller, lighter and cheaper than a standard dual-winding transformer, but it does not provide electrical isolation

Capicitance and Capacitors

- Electronic device that can store electrical energy
- plates
- dielectric
- DC current cannot flow through
- Farad (F)
- Variable capacitor



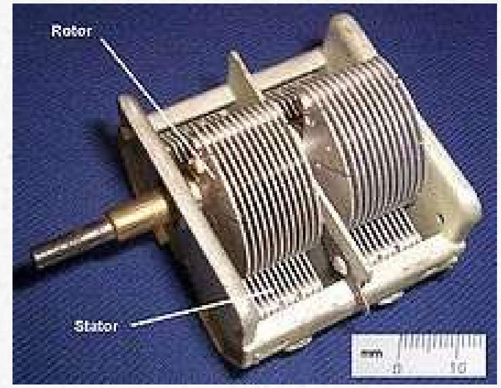
Capacitors



- In the hydraulic analogy, a capacitor is analogous to a rubber membrane sealed inside a pipe. This animation illustrates a membrane being repeatedly stretched and un-stretched by the flow of water, which is analogous to a capacitor being repeatedly charged and discharged by the flow of current

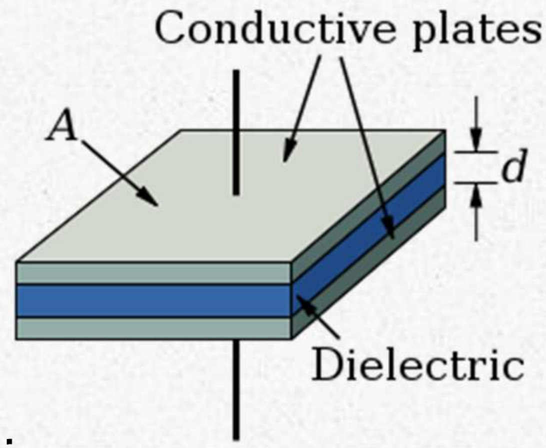
Capacitors

- stator and rotor
- voltage variable capacitor (VVC)
- varactor (type of diode)
- compression trimmer
- electrolytic capacitors



Capacitance

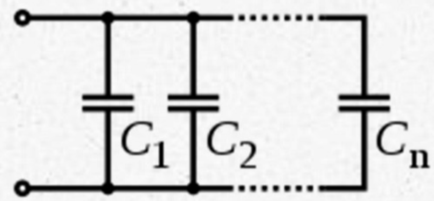
- effective area of plates
- distance between plates
- dielectric material
  - dielectric constant (relative static permittivity=1 in a vacuum)



$$\varepsilon A/d$$

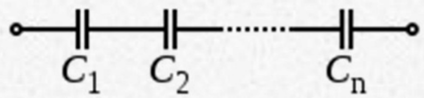
Capacitors in Parallel

$$C_{eq} = C_1 + C_2 + \cdots + C_n$$



- Opposite to resistors and inductors
- C_1=8F; C_2=16F and C_3=8F
- $C_{eq} = (8 + 16 + 8\,)F = 32F$

Capacitors in Series



- Opposite to resistors and inductors
- $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots + \frac{1}{C_n}$
- So if C_1=2F; C_2=4F; C_3=6F; C_4=8000mF
- $\frac{1}{C_{eq}} = \frac{1}{2F} + \frac{1}{4F} + \frac{1}{6F} + \frac{1}{8F} = \frac{12+6+4+3}{24F} = \frac{25}{24F}$
- $C_{eq} = 0.96\text{F}$

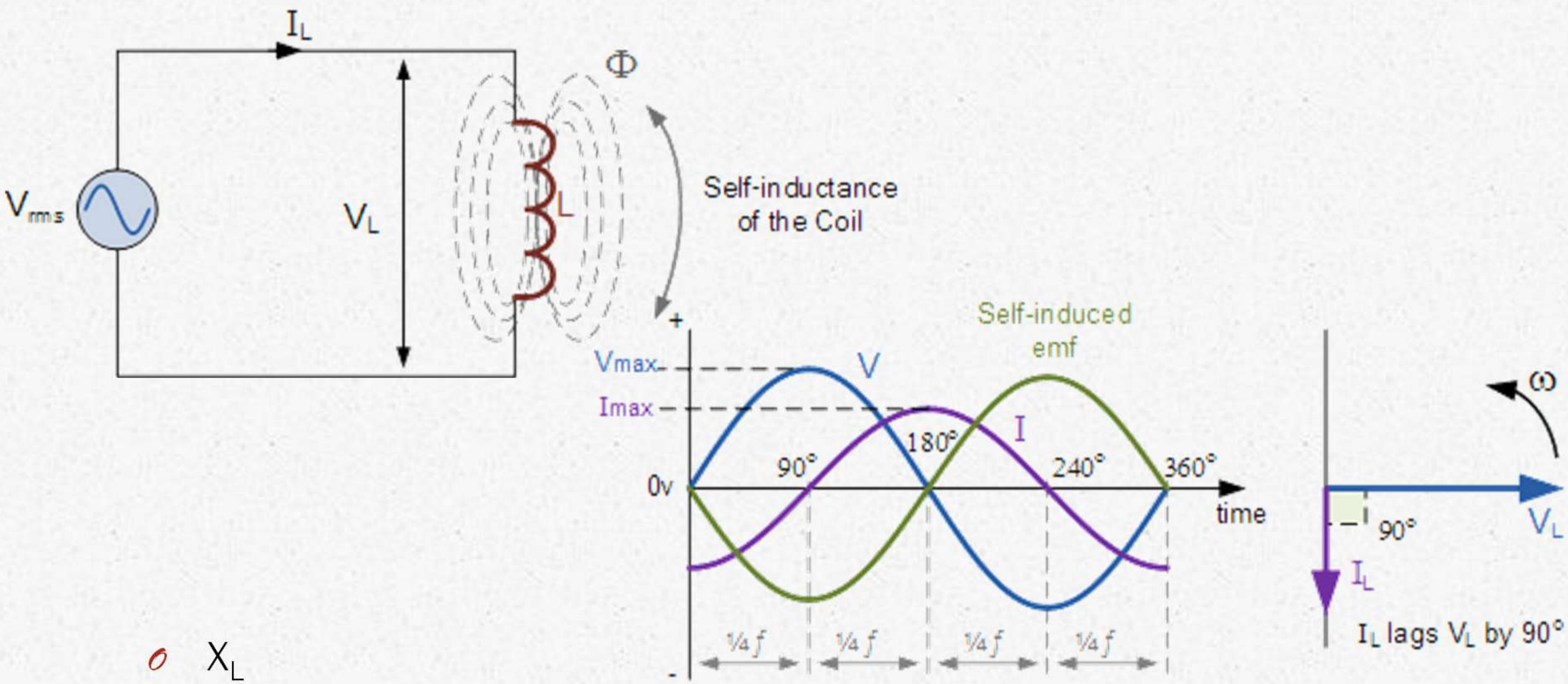
Capacitors

- Working voltage or voltage rating
  - maximum voltage expressed as VDC capacitor can sustain continuously without displaying excessive leakage or breaking down – i.e. charge jumping from negative plate to positive plate
  - such jumping damages air variable capacitors and destroys all others
- Surge voltage
  - electrolytic
  - max voltage sustained during start up of the circuit (applies to circuits with tubes)

Reactance

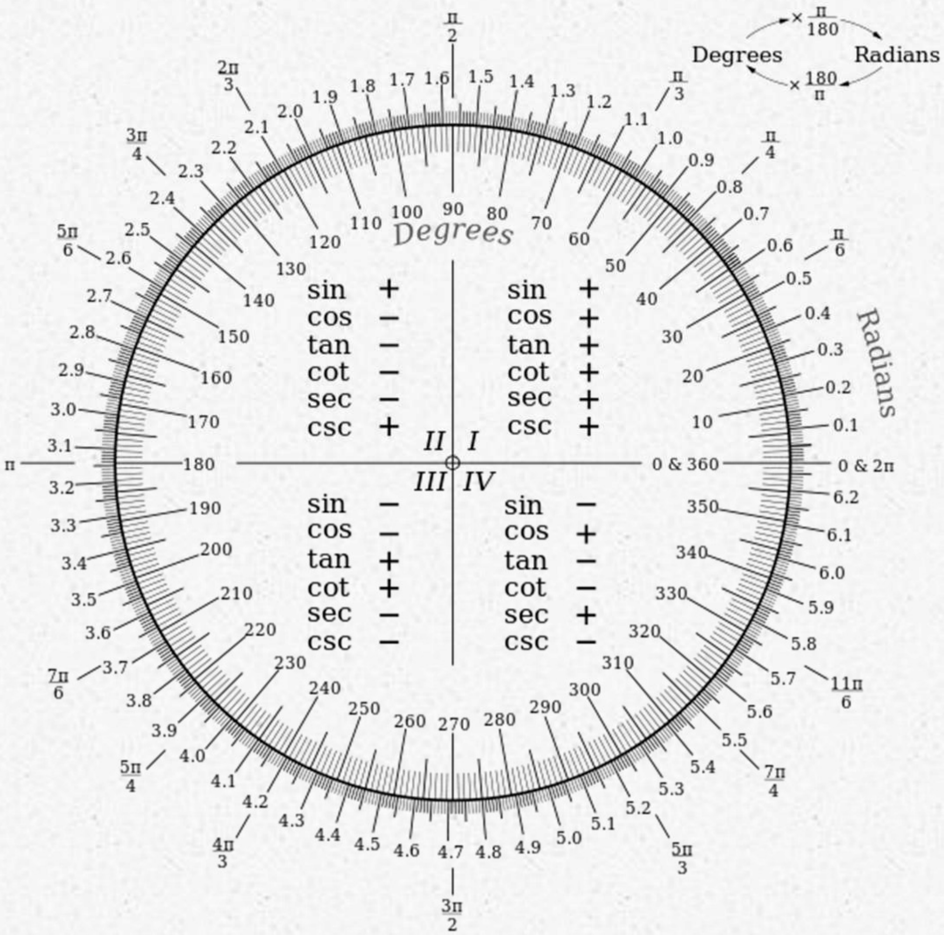
- Reactance
  - opposition to the flow of alternating current (AC)
  - opposition has no effect on flow of DC in a circuit
  - Similar to effect of resistance in a DC circuit
  - units are Ohms
  - No energy is dissipated in a reactance but it is rather stored and returned to circuit

Inductive Reactance



- X_L
- Inductive reactance is the opposition offered to AC by an inductor
- current lags voltage (phase difference) of 90 degrees or $\frac{\pi}{2}\ radians$

Radians



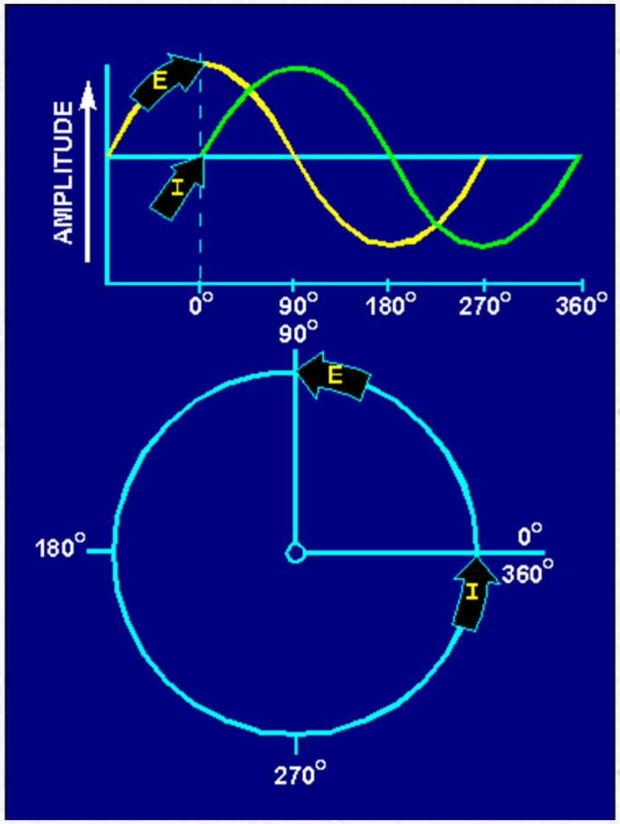
Just remember there are 2π radians in 360 degrees.

Inductive Reactance

$$X_L = \omega L = 2\pi f L$$

- f is the frequency in Hz (i.e. rate of change of AC)
- higher frequency, greater inductive reactance
- L inductance (in Henries) is intrinsic to the coil
- as inductance goes up so does inductive reactance
- direct relationship

Inductive Reactance



Capacitive Reactance

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

- X_C
- Capacitive reactance is the opposition offered to AC by a capacitor
- current <u>leads</u> voltage (phase difference) of 90 degrees or $\frac{\pi}{2}\ radians$
- A frequency goes up, capacitance reactance goes down
- As the capacitance goes down, the capacitive resistance goes up
- inverse relationship

Impedance

- When a circuit contains both resistance and reactance the opposition to the flow of AC in the circuit is called impedance (Z)
- If AC flows in a circuit with impedance then the value of impedance will be greater than the value of the resistance.

$$X = X_C + X_L \qquad Z = R + jX$$

- $|\boldsymbol{Z}| = \sqrt{R^2 + X^2}$

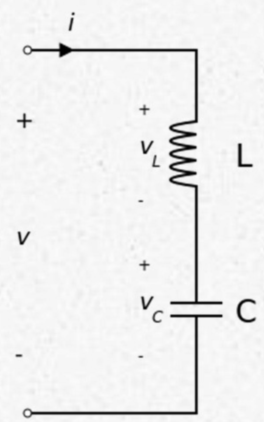
Impedance

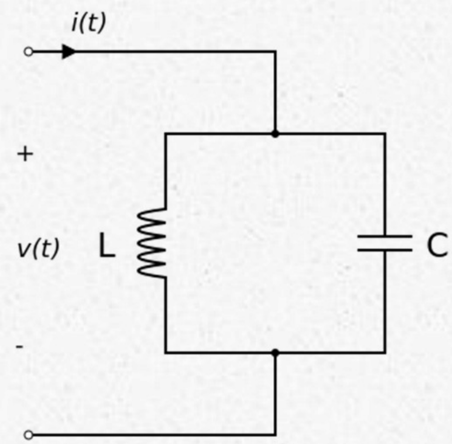
- Impedance matching
  - circuit to which input is connected has same impedance in Ohms as the input circuit
  - circuit to which output is connected has same impedance as the device it feeds into
- Transformers are used to match impedances
- $\frac{Z_S}{Z_p} = \frac{(N_S)^2}{(N_P)^2}$
- More on this when we get to Transmission Lines

Resonance

- Resonance is the situation when the inductive reactance X_L in a circuit is equal to the capacitive reactance X_C and these factors cancel out
- This occurs only at one frequency, the resonant frequency
- $f_r = \frac{1}{2\pi\sqrt{LC}}$

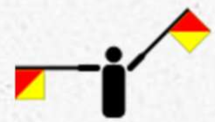
Tuned Circuits





- Series resonant circuit – min impedance at resonant frequency
- Parallel resonant circuit – max impedance at resonant frequency between the two nodes
- tuned circuit to minimize or maximize losses
- filtering of frequencies

Q



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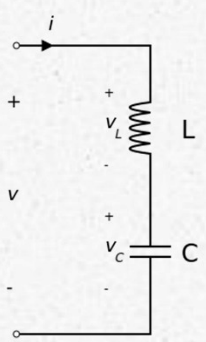
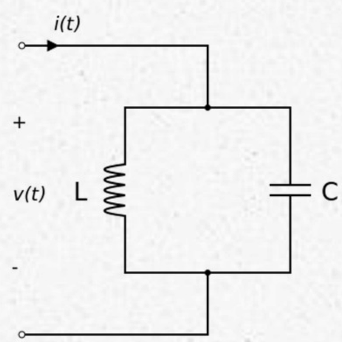
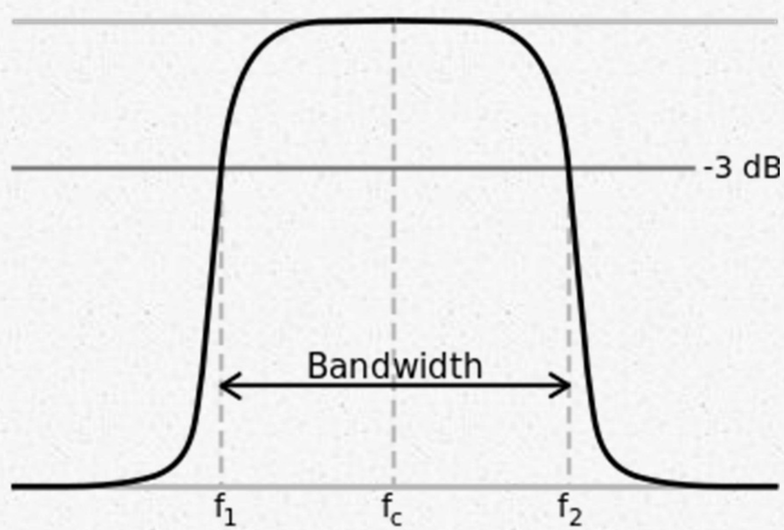
Q

- Quality factor
- circuit resistance tends to remove some of the energy from the resonant circuit
- resistance effects the bandwith







$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

$$Q = R\sqrt{\frac{C}{L}}$$

Conclusion

- Chapter 2 – Basic Electrical Theory
- Chapter 3 – Ohm's Law and Power
- Chapter 4 – Inductors and Capacitors