Circuits

Current

Conductivity

- Unit of conductivity is the in **Siemens/m**, while **Conductance** is the reciprocal of resistance and has unit of **Siemens**.
- Metallic conductivity: seen in solid metals or molten metals with some salts. Characterized by the **metallic bond**, which can be visualized as a sea of electrons flowing over a lattice of metal cations.
  - Good electrical and thermal conductors
  - Metal atoms can easily lose one or more of their outer electrons
- Electrolytic Conductivity: This depends on the strength of the solution, but is otherwise similar to metallic conductivity.
  - Conductivity can be measured by placing the solution as a resistor and measuring the change in voltage across the solution. Can also be used to determine the ionic concentrations of solution since it is directly related to conductivity.

Current

- The current is considered the flow of positive charge, even though only negative charges move. Has unit of **ampere** [1 A = 1 C/s] $I = \frac{Q}{\Delta t}$
- Electrons move from a point of lower electric potential to that of a higher electric potential. Thus the direction of the current is opposite to that of the electron flow.
- Direct Current (DC): charge flows in one direction only
- Alternating Current (AC): flow changes direction periodically.
- Potential Difference (Voltage): can be produced by an electrical generator (galvanic cells)
  - Voltage is called the **electromotive force** in units of J/C.

Circuit Laws

Charge and energy must be fully accounted for at all times and can be neither created nor destroyed.

- Kirchhoff's Junction Rule: At any junction in a circuit, the sum of currents directed into that point equal the sum of currents leaving that point.
- Kirchhoff's Loop Rule: Around any closed loop, the sum of voltage sources will always be equal to the sum of voltage drops.

Resistance

The opposition within any material to the movement and flow of charge. Conductive materials that off a moderate amount of controllable resistance are called **resistors.**

Properties of Resistors

- Depends on resistivity, length, cross-sectional area and temperature: $R = \frac{\rho L}{A}$
- Resistivity: Characterizes the intrinsic resistance of materials [Ω•m]

- Length: a longer resistor means that the electrons will have to travel a greater distance. If length doubles, resistance doubles.
- Cross-Sectional Area: Increases the number of **conduction pathways** through the resistor, which subsequently reduces resistance.
- Temperature: Most conductors have greater resistance at higher temperatures. Higher temperature increases the amount of thermal vibration which leads to greater resistance to electron flow.

Ohm's Law and Power

- Ohm's Law: For a given resistance, the voltage drop across a resistor will be proportional to the magnitude of the current.

$$V = IR$$

- Even emf sources have **intrinsic resistance**, so the actual voltage of a battery can be calculated from: $V = E_{cell} - ir_{int}$
- Measuring Power: The following equation provides that rate at which energy is dissipated by a resistor: $P = IV = I^2R = \frac{V^2}{R}$

Resistors in Series and Parallel

- Resistors in Series: Current travels through each resistor in order to return to the cell.
  - Voltage Drop across cell will be: $V_s = V_1 + V_2 + V_3 + .. + V_N$
  - Resistance in total: $R_s = R_1 + R_2 + R_3 + .. + R_N$
- Resistors in Parallel: Electrons have a choice regarding which path they take. The resistors are all wired with a common high-potential terminal and a common low potential terminal. Since they share these common terminals the voltages are the same across each division of resistors.
  - This functions to reduce the overall resistance by providing a greater number of conduction paths.
  - R_P will always decrease as more resistors are added.
  - When n identical resistors are wired in parallel, the equivalent resistance becomes R/n.

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N}$$

Capacitance and Capacitors

- Capacitors have the ability to hold charge at a particular voltage. Will focus on parallel plate capacitor. Functions to store an amount of energy in the form of charge.

Properties of Capacitors

- Positive charges buildup to plate connected to the positive terminal, and negative charges buildup on plate connected to negative terminal. These plates can store a charge at a particular voltage.
- Capacitance of a capacitor is the ratio of the magnitude of the charge stored on one plate to the potential difference across the capacitor. $C = \frac{Q}{V}$

- Has units of the **farad** [1 F = 1 C/V]. Usually given in microfarads (10^{-6}) or picofarads (10^{-12}).
- Parallel plates: $C = \varepsilon_0 \left(\frac{A}{d}\right)$: $\varepsilon_0$is the permittivity of free space (8.85 x 10^{-12} F/m)
  - Separation of charge sets up a **uniform electric field**: $E = {}^{V}/_{d}$ with a directional arrow pointing from the positive plate to the negative plate.

- Potential Energy: $U = 1/2 * C * V^2$

Dielectric Materials

- Just another way of saying insulation. When a dielectric material is placed between the plates of a capacitor, it increases the capacitance by a factor called the **dielectric constant (κ)**.
- A dielectric material will never decrease the capacitance.
- Dielectrics in Isolated Capacitors: Voltage across the capacitor decreases when dielectric material is placed between the plates since the material shields the opposite charges from each other.
  - Increases capacitance through a decreased in voltage
- Dielectrics in Circuit Capacitors: Charge on capacitor increases when material is placed within it. Voltage must remain constant, so instead the charge increases.

Capacitors in Series and Parallel

- Series: Total capacitance decreases since the capacitors must share the voltage drop in the loop and therefore cannot store as much charge. These acts like an equivalent capacitor with a much larger distance between the plates.

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_N}$$

- Parallel: Voltage across each parallel capacitor is the same and this increase the equivalent capacitance.

$$C_p = C_1 + C_2 + \cdots + C_N$$

Meters

- Ammeters: used to measure the current at some point within a circuit. These require the circuit to be on, and must be put in series with the current that is to be measured.
  - Ideal ammeters will have zero resistance and no voltage drop across them
- Voltmeters: Requires circuit to be active, uses magnetic properties of current carrying wires. Measures voltage drop across two points in a circuit and they must be wired in parallel to these two points.
  - An ideal voltmeter would have infinite resistance.
- Ohmmeters: Do not require a circuit to be active. Usually have own battery with a known voltage, the ohmmeter then acts like an ammeter and uses Ohm's law to find the resistance since the voltage is already known.