Chapter 21 Electric Current and Direct Current Circuits

Section 21-1

- Current $\left(I = \frac{\Delta Q}{\Delta t} \right)$ is equal to the rate at which charge flows through a cross sectional area – this area could be in a wire or an area of space through which charged objects are moving. The MKS unit of current is the ampere = 1 coulomb/sec. Conventional current flow is taken to be the direction in which positive current flows (this is opposite to the actual motion of electrons in a wire).

- Charge has to be "pushed" through a circuit, because the wire material *resists* the motion of charge. In order for current to flow in a circuit, there must be a source of potential difference. This potential difference can be provided by a battery or a generator. In a circuit diagram, this source is labeled the emf (= the electromotive force) even though it is a source of potential difference (units of volts) and not a force. A potential difference means that there is a difference in potential energy between those two points. This difference in potential energy is supplied by the battery (or source of emf) and is "used up" by the charge as it does work in passing through resistive material.

- Batteries in Series and Parallel:

  Current: In a series connection of batteries , the current passing through each battery is the same. In a parallel connection of batteries, the current going in splits up, and part of that current will pass through each battery.
  Voltage: In a series connection of batteries, the total voltage across the series connection is divided across each battery and part of the total voltage will be produced by each battery ($V_S = V_1 + V_2 + ...$[the terminal direction *is* important]). In a parallel connection of batteries, the voltage across each battery is the same.

Section 21-2

- Not all materials have resistance that follows Ohm's Law, but all the resistive materials we will see in this chapter will follow Ohm's Law. Ohm's Law specifies that current is directly proportional to voltage for materials whose resistance is constant $\left(I = \frac{V}{R} \right)$. The resistance of a piece of material is given by $R = \frac{\rho L}{A}$, where L is the length, A is the cross sectional area, and ρ is the resistivity (which depends on the type of material).

Section 21-3

- Work is done over time in moving a charge around a circuit. The work per unit time is equal to the power which must be supplied to the charge to expend in the charge's motion through the resistor. This power is given by $P = I V = I^2 R = V^2/R$ (the last two for Ohm's Law materials).

- Power multiplied by time equals energy, thus $P \times t = I^2 R \times t$ = the energy expended in moving the charge through the potential difference V. $I^2 R$ is referred to as Joule heating, but remember that $I^2 R$ is power, not energy.

Section 21-4

- **Series** Resistors in series add ($R_S = R_1 + R_2 + ...$). The expression for the equivalent resistance of a series connection is derived by applying the conservation of energy.
  Parallel Resistors in parallel add in reciprocal $\left(\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + ... \right)$. The expression for the equivalent resistance of a parallel connection is derived by applying the conservation of electric charge.

  Current: In a series connection of resistors, the current passing through each resistor is the same. In a parallel connection of resistors, the current going in splits up, and part of that current will pass through each resistor.
  Voltage: In a series connection of resistors, the total voltage across the series connection is divided across each resistor and part of the total voltage will fall across each resistor. In a parallel connection of resistors, the voltage across each resistor is the same.

- Circuits which contain combinations of resistors in series and parallel can be analyzed in parts. Look for a part of the circuit that contains only a series or only a parallel connection. Reduce that part to an equivalent resistance and then work on the next part. Continue until the whole circuit is reduced to a single equivalent resistance.

- A battery is not a pure source of potential difference. A battery has internal resistance so that the terminal voltage (the actual potential applied to a circuit) is equal to the emf minus the voltage drop across the internal resistance of the battery ($V = \mathcal{E} - I r = I R$).

Section 21-5

- Kirchhoff's Rules allow us to analyze circuits which cannot be reduced to a single equivalent resistor. Usually this means there must be two emfs present in two different branches, but this is not always the case– there are some resistor networks which cannot be reduced to a single equivalent resistor. Kirchhoff's Rules are:

1) **The Junction (or Current) Rule**– The sum of currents going into any point in a circuit must be equal to the sum of currents coming out of that same point: ($\Sigma I_{\text{entering}} = \Sigma I_{\text{leaving}}$).

2) **The Loop (or Voltage) Rule**– The sum of potential changes (ΔV) around any closed loop in a circuit must add up to zero. ($\Delta V_{\text{closed loop}} = 0$)

   In terms of problem solving, the first rule will provide fewer equations to work with than the second rule– e.g., Fig.21-14 has three branches, but only one current equation. On the other hand, for this same circuit, you could write down three voltage equations (although two of those would contain repeated information).

Tips on applying Kirchhoff's Rules:

1) In applying the voltage rule, remember that the direction that you choose to follow a loop is arbitrary, but once you start a loop you must follow it in the same direction until you return to the loop's starting point. The loop direction determines the sign of each voltage change (ΔV): going through a battery from + to – is a voltage drop, going through a resistor from low potential side to high potential side is a voltage increase.
2) To apply the current rule, you must first assume a current direction in each branch. Don't worry about guessing wrong. If you do, only the sign of the solved-for current will be wrong (i.e. negative).

Section 21-6

- **Series** Capacitors in series can be reduced to a single equivalent capacitance: $\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$

  Parallel Capacitors in parallel can be reduced to a single equivalent capacitance: $C_P = C_1 + C_2 + \ldots$
  Capacitors in series and parallel combinations can also be reduced to a single equivalent capacitor.

  Charge: In a series connection of capacitors, each capacitor's positive plate has the same charge. In a parallel connection of capacitors, the charge splits up, and part of that charge will appear on each capacitor.
  Voltage: In a series connection of capacitors, the total voltage across the series connection is divided across each capacitor and part of the total voltage will fall across each capacitor. In a parallel connection of capacitors, the voltage across each capacitor is the same.

- When connected to a DC battery, charge eventually stops flowing (current = 0) onto the capacitor when the potential across the capacitor is equal to the battery's potential.

Section 21-8

- Ammeters are devices that measure the current passing *through* something (like a battery or resistor), so an ammeter must be connected in series with a circuit element. Voltmeters are devices that measure potential difference (or drop) *across* something (like a battery or resistor), so a voltmeter must be connected in parallel across a circuit element.