Networks are based on electronic circuits, whose name derives from the Latin word for a circle or loop. As you probably already know, the simplest form of circuit consists of a generator, line and resistor, such as a battery, wire and lightbulb. The schematic representation of this is as follows:

**Ohm’s Law**

All components of a circuit are described by a simple principle known as Ohm’s Law. It simply states that voltage across a resistor equals the current through it times a quantity known as resistance.

\[ V = IR \]

Voltage is measured in volts (V), current in amps (A) and resistance in ohms (Ω). (These units are named after the scientists Volta, Ampere and Ohm)

**Kirchhoff’s Law**

**Voltage:**
The total voltage in a circuit must add up to zero. This means that voltage at the source must be equal to the total voltage drop across the resistors in a circuit. Ohm’s law \( V = IR \) also governs the magnitude of the voltage drop across each resistive element in a circuit. (note: short wires also have a resistance, however, this is insignificant compared to the R of a resistor – we will address long wires later)

**Current:**
The sum of the currents flowing to any one point in a circuit, known as a node, must be zero.

\[ I_1 + I_2 + I_3 = 0 \]

This means that if \( I_1 \) is +1 amp, and \( I_2 \) is +2 amps then \( I_3 \) must be –3 amps (in other words, \( I_3 \) is 3 amps flowing away from the node)

**Determining Resistance**

If you have more than one resistor in a circuit, they can be combined into a single equivalent resistance, \( R_T \). The method for combining depends on whether resistors are in series or in parallel.
If resistors are in *series*:

\[ R_{\text{Total}} = R_1 + R_2 + R_3 \]

Current, \( I \), is the same through each resistor, and equal to: \( I = \frac{V_{\text{Source}}}{R_{\text{Total}}} \)

If resistors are wired in *parallel*:

\[ \frac{1}{R_{\text{Total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \]

Voltage, \( V \), is the same across each resistor and equal to \( V_S \).

If you have a combination, convert the parallel portion of the circuit to one resistance, and then add the resistors as if they were in series.

**EXAMPLE**

\[ V_{\text{Source}} = 12V \]
\[ R_1 = 1000\Omega \quad R_2 = 400\Omega \quad R_3 = 400\Omega \]

First convert \( R_2 \) and \( R_3 \) to a single resistance, \( R_{\text{parallel}} \):

\[ \frac{1}{R_{\text{parallel}}} = \frac{1}{R_2} + \frac{1}{R_3} \]
\[ \frac{1}{R_{\text{parallel}}} = \frac{1}{400\Omega} + \frac{1}{400\Omega} \]
\[ \frac{1}{R_{\text{parallel}}} = \frac{2}{400\Omega} \]
\[ R_{\text{parallel}} = 200\Omega \]

Now add \( R_1 \) and \( R_{\text{parallel}} \):

\[ R_1 + R_{\text{parallel}} = R_{\text{Total}} \]
\[ 1000\Omega + 200\Omega = 1200\Omega \]

Use \( R_{\text{Total}} \) to determine the current through the loop:

\[ V_{\text{Source}} = I_{\text{Total}}R_{\text{Total}} \]
\[ 12V = I_{\text{Total}} \times 1200\Omega \]
\[ I_{\text{Total}} = .01A \]

Because \( R_1 \) and \( R_{\text{parallel}} \) were in series, this is the current that passes through each of them. To find the voltage through each resistor, use Ohm’s Law:

\[ V_1 = I_{\text{Total}}R_1 \]
\[ V_1 = .01A \times 1000\Omega \]
\[ V_1 = 10V \]

\[ V_{\text{parallel}} = I_{\text{Total}}R_{\text{parallel}} \]
\[ V_{\text{parallel}} = .01A \times 200\Omega \]
\[ V_{\text{parallel}} = 2V \]

notice that the voltage drops add up to 12V = \( V_{\text{Source}} \).

To find the current through and voltage across \( R_2 \) and \( R_3 \) you must use what you know about the voltage, \( V_{\text{parallel}} \), across the two of them. Because they are wired in parallel, the voltage across each of them is the same. It is also equal to \( V_{\text{parallel}} \):

\[ V_2 = V_3 = V_{\text{parallel}} \]
\[ V_2 = 2V \]
\[ V_3 = 2V \]
To find the current through each, again use Ohm’s law:

\[ V_2 = I_2 R_2 \]
\[ 2V = I_2 \times 400\Omega \]
\[ I_2 = .005 \, \text{A} \]

\[ V_3 = I_3 R_3 \]
\[ 2V = I_3 \times 400\Omega \]
\[ I_3 = .005 \, \text{A} \]

Resistance of a device can be a function of different properties, such as temperature. In a wire, resistance is dependent upon the material used, the length of the wire, and its cross-sectional area:

\[ R = \frac{\text{resistivity of the material} \times \text{length of wire}}{\text{cross-sectional area of the wire}} \]

**Joule’s Law**

Another important equation relating to all circuits is Joule’s Law. It states:

\[ P = VI \]

And, knowing that \( V = IR \), we can substitute to create another relationship:

\[ P = I \times (IR) \]

\[ P = I^2 R \]

From this, one is able to determine power losses due to resistance at different current levels.

Thomas Edison worked with these equations to help him develop his vision of a great New York network of electricity.

**Electromagnetism**

Faraday observed that when current flows through a wire that is in a magnetic field, this wire experiences a force in a direction perpendicular to both the magnetic field and the current flow. The magnitude of the force on this wire is:

\[ F = iLB \]

Where \( F \) is the force on the wire, \( i \) is the current running through the wire, \( L \) is the length of wire that is in the magnetic field, and \( B \) is the magnetic field strength.

This observation serves as the fundamental basis for many electromagnetic devices including motors, loudspeakers and electromagnetic meters.