The following is a summary of the analog electronics we have studied following the standard R, C, L circuits. (We have basically left off inductors in the interest of time.)

**Diode:**  
Allows current flow in one direction only.

Detail: there is a 0.6 V voltage drop in that direction, you can flow current in opposite direction with large enough potential difference (breakdown voltage). A zener diode is one which has a manufactured breakdown voltage which is meant to be utilized.

Along with an RC filter, a diode enables one to make a DC power supply.

**Transistor:** (e.g. 4123)  
Amplifier or switch.

Detail: essentially 2 diodes put together opposite each other with wires at each end and one in the middle. Comes in 2 varieties: PNP and NPN, depending on which way around the diodes are.

Amplifies current or current and voltage. Current amplification typically around 100 times. Often used as a current source (rather than the standard voltage source power supplies we use).

**Operational Amplifier (Op-Amp):** (e.g. 741)  
High gain voltage amplifier. Inverting or non-inverting.

Detail: integrated circuit: multi-transistor circuit with R’s, C’s imprinted on a chip.  

Maximum amplification (“+/∞”) is actually the saturation voltage, which is just below the voltage powering the op-amp. With negative feedback, is described by the two Golden Rules. Resistors can then fix the gain.
Op-Amp can run as a differential amp (output is proportional to difference between the 2 inputs). A high gain differential amplifier will saturate at +/-\infty depending on which input is bigger. This is called a comparator.

**Comparator:** (e.g. 311)

High-gain differential amp: outputs high or low depending on which of 2 inputs is bigger.

![Comparator diagram](image)

Detail: specialized op-amp circuit. High speed response (high slew-rate). Saturation voltages, high and low, are set with voltage sources.

Usually a reference voltage (Vref) is set (on V+ or V-) and the other (Vin) can be varied.

**Schmitt Trigger:** At zero crossing (2 inputs equal), comparator will oscillate between hi and lo because of noise, so if the reference signal (Vref) is on V+, we can use positive feedback to make the reference move away from the input voltage (on V-) when V- crosses (becomes < or >) Vref. e.g. if V- is being reduced(increased) toward V+, when it reaches V+, V- is then increased(reduced) so that V- will not cross V+ again unless you start to increase(reduce) V-.

**Square Wave Oscillator:** Add negative feedback through a capacitor to the Schmitt trigger, so that every time the reference signal (on V+) is crossed by V-, the charging/discharging state of the capacitor is changed to bring V- back toward V+. Note that this is usually done with the reference (V+) at ground, and no external input on V+ since the input will come from the voltage on the capacitor which comes from the feedback from Vout. e.g. start with V- = 0, so that the voltage on the capacitor is zero, the output is high, and so V+ > 0 (due to positive feedback); so then the output will charge the capacitor, bringing V- (= Vcap) up to V+. When Vcap > V+, the output will go low which will trigger two things: V+ < 0 due to positive feedback, and the capacitor will begin to charge negatively (or discharge) from the output, so that V- (= Vcap) again goes toward V+; when Vcap becomes less than V+, the output will go hi again, and the process starts over. Note that Vout will be hi during the charging and lo during the discharging, so the output gives a square wave oscillator.

**Oscillator:** (e.g. 555)

Square wave oscillator.

![Oscillator diagram](image)

Detail: IC. Period and duty cycle (% of time output is hi) are controlled with external R’s and C chosen to complete standard oscillator circuit.

Can be modified for triangle/sine wave output, or just use VCO IC….