ENGR 2219 – Linear Circuits I
Electronics – Diodes

Diodes
- Have two terminals: Anode and Cathode
- Made up of a p-type (Anode) and n-type (Cathode) layer

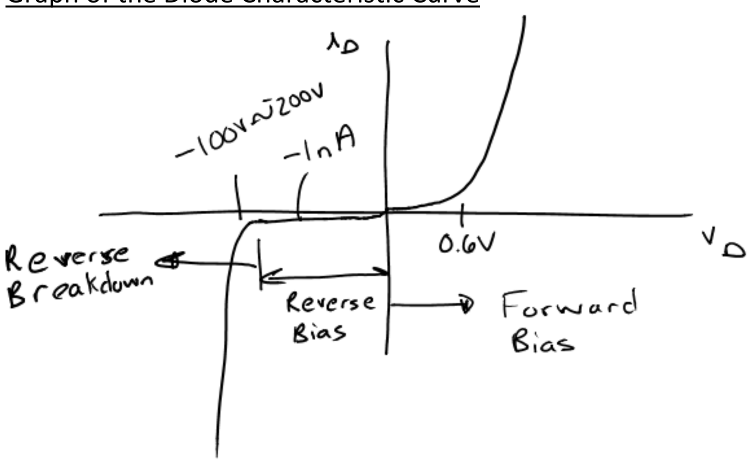
Symbol

Characteristic Regions of a Diode
- **Forward Bias**: If $i_D > 0$, then current flows easily through the diode

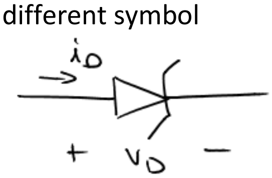
- **Reverse Bias**: If $v_D < 0$, but not very large, then the current is very small

- **Reverse Breakdown**: If $v_D < 0$ and is very large, then the current becomes large and negative (OK if the heat does not get too high)

Graph of the Diode Characteristic Curve

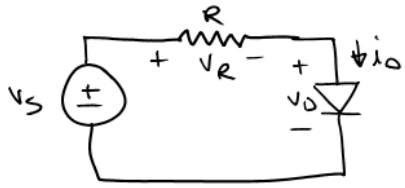


Zener Diode
- Intended to operate in the reverse breakdown region
- Voltages are much smaller (3, 5, 12… Volts)
- Used when a constant voltage is needed
- Has a different symbol



Load Line Analysis of a Diode

- Places a diode in a basic circuit
- Use KVL to get the equation for the load line
- Use the load line and diode characteristic curve to solve for the operating voltage and current of the diode in the circuit

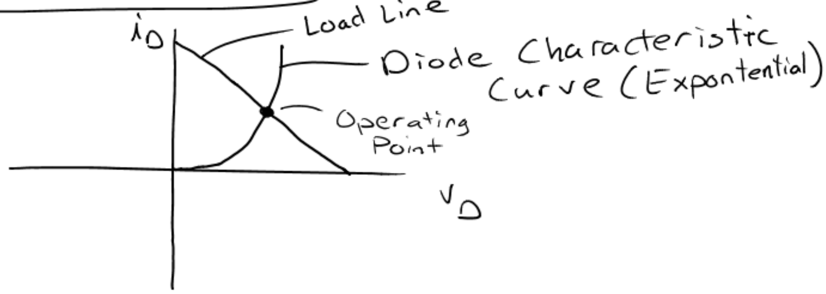


KVL (CW)

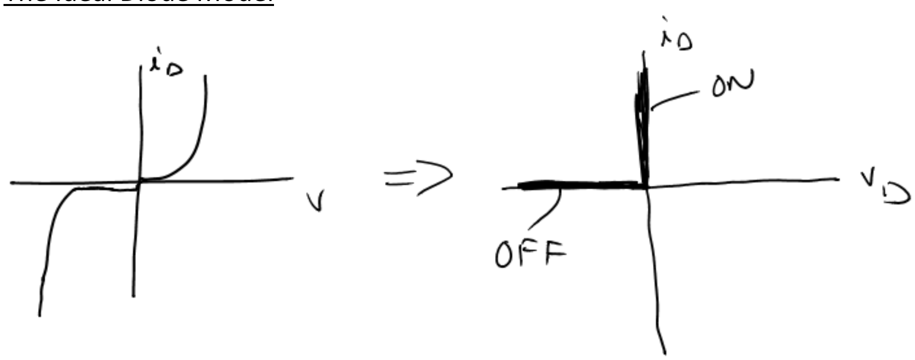
$$-v_S + v_R + v_D = 0$$

$$-v_S + i_D R + v_D = 0$$

$$\boxed{i_D = -\frac{1}{R} v_D + \frac{v_S}{R}}$$ Load Line



The Ideal Diode Model



- Two operating states
  - **ON**: Perfect conductor (v_D = 0), i_D > 0
  - **OFF**: Open circuit (i_D = 0), v_D < 0

Assumed State of a Diode

- Either ON or OFF
- May not know the state in advance
- Assume a state, perform circuit analysis, and check if the assumed state is correct

    ON: Set $v_D = 0$, Check if $i_D > 0$

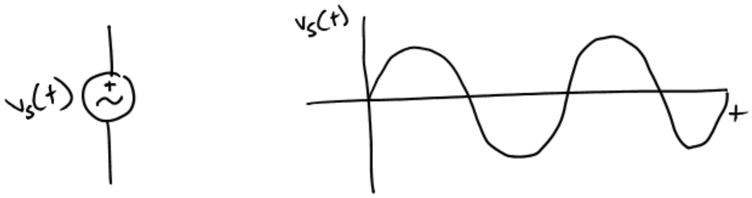
    OFF: Set $i_D = 0$, Check if $v_D < 0$

- For multiple diode circuits, all diodes must pass the checks for the assumed state to be correct

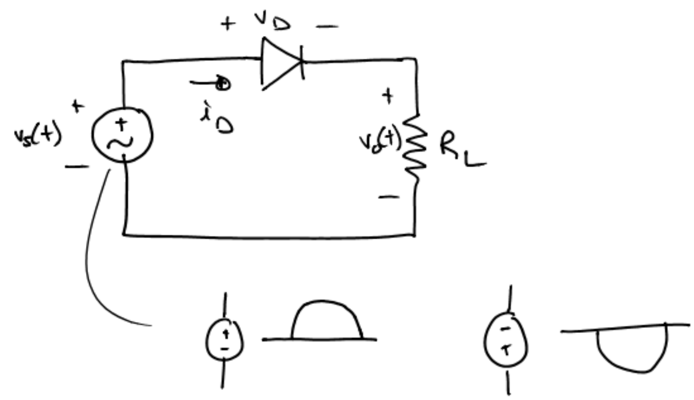
Diode Applications

Rectifiers

- Used to convert AC to DC
- AC: Not constant (sine wave)



- Half-Wave Rectifier



KVL

$$-v_s(t) + v_D + v_o(t) = 0$$

$$-v_s(t) + v_D + i_D R_L = 0$$

If $v_s > 0$ Diode => ON

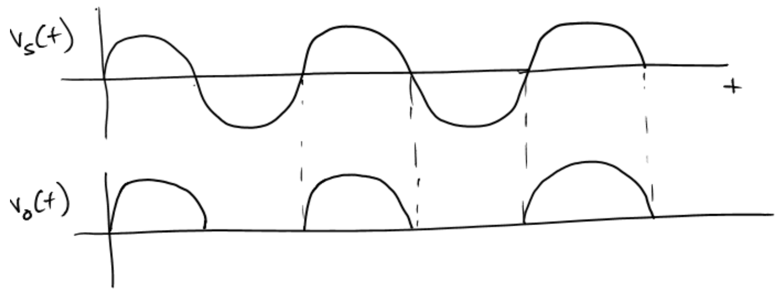
$$i_D = \frac{v_s(t)}{R_L}$$

$$v_o(t) = i_D R_L = \left(\frac{v_s(t)}{R_L}\right)(R_L)$$

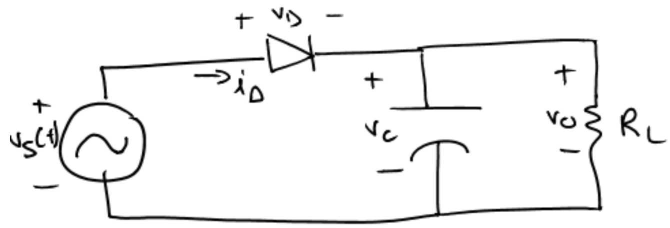
$$v_o(t) = v_s(t)$$

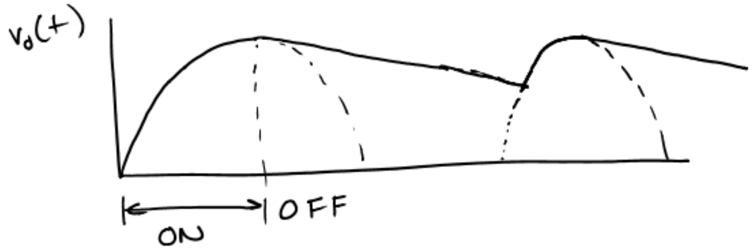
If $v_s < 0$ Diode => OFF

$i_D = 0$ => $\boxed{V_o = 0}$

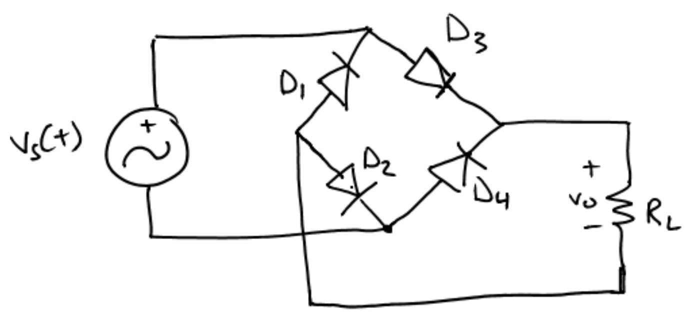


- Half-Wave Rectifier with smoothing capacitor





- Full-Wave Bridge Rectifier



$v_s > 0$

$D_2 = ON$

$D_3 = ON$

$D_1 = OFF$

$D_4 = OFF$

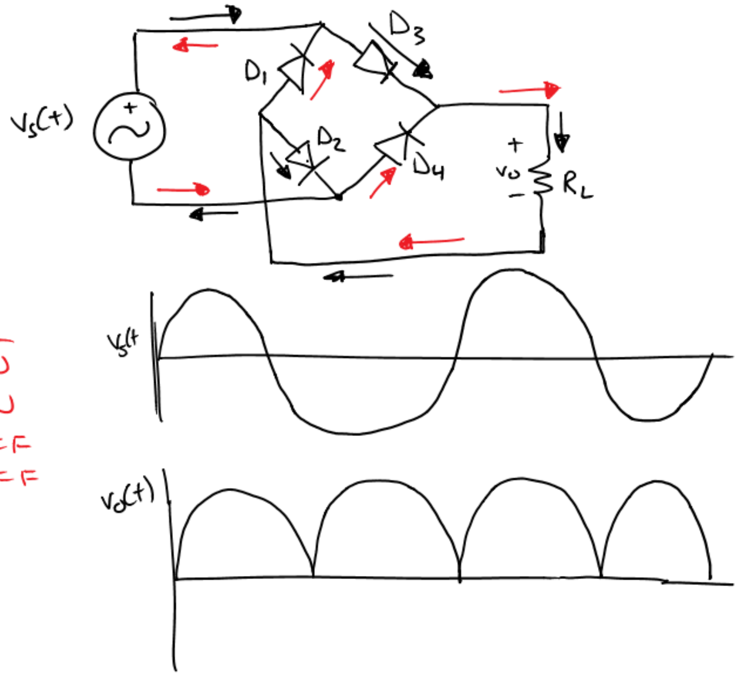
$v_s < 0$

$D_1 = ON$

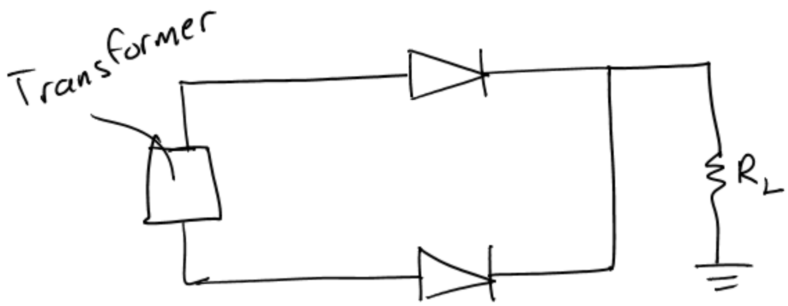
$D_4 = ON$

$D_2 = OFF$

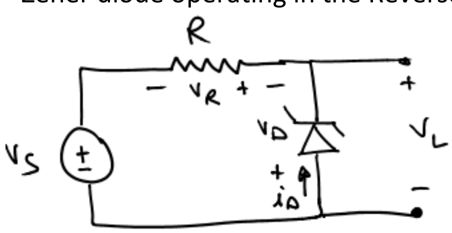
$D_3 = OFF$



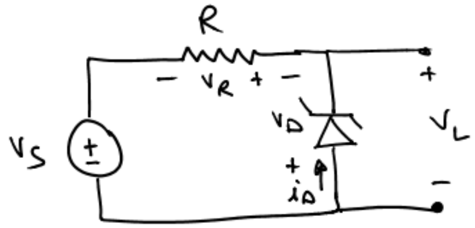
- Full-Wave Rectifier



- Voltage Regulator Circuit
    - Zener diode operating in the Reverse Breakdown Region



$$V_L = -V_D$$

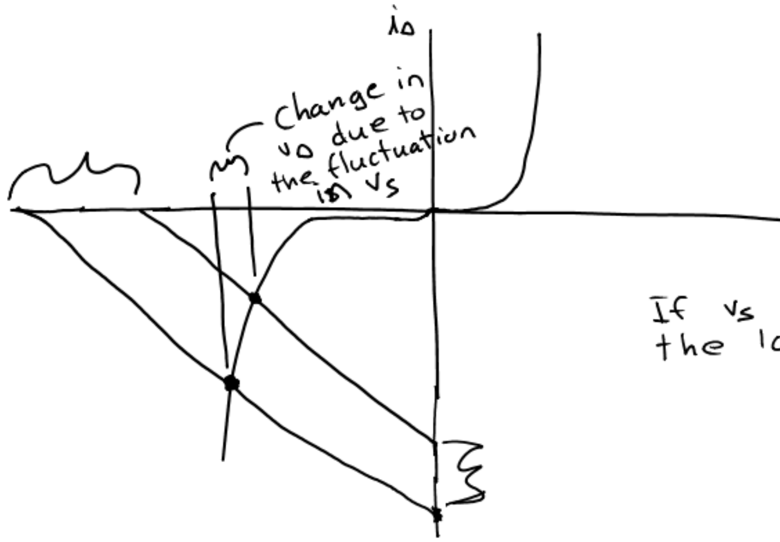


$v_L = -v_D$

KUL (cw)

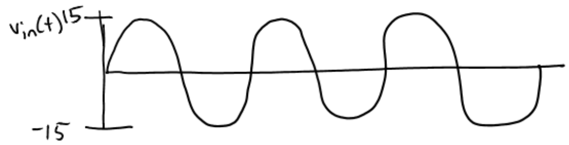
$$-v_S - i_D R - v_D = 0$$

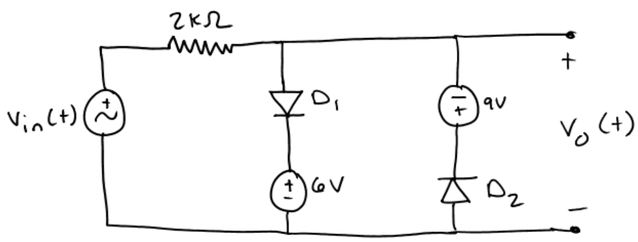
$$i_D = -\frac{1}{R} v_D - \frac{v_S}{R}$$



If v_s fluctuates, then the load line will shift

- Clipper Circuit
    - Wave shaping circuit
    - Transform one waveform into another
    - A portion of the input signal is "clipped" off
    - Function generators





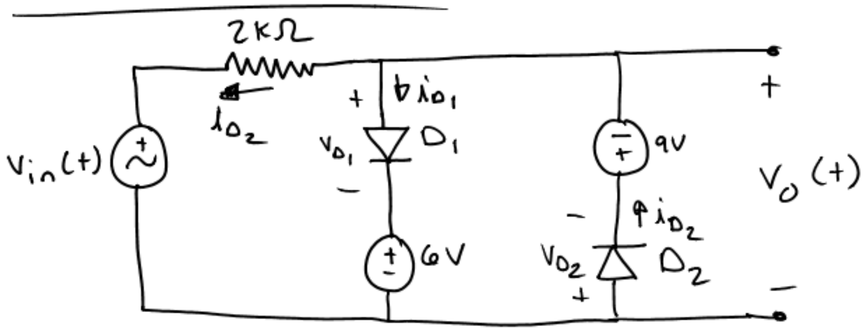
Cases

$-15V < v_{in} < -9V$

$-9V < v_{in} < 6V$

$6V < v_{in} < 15V$

$-15V < v_{in} < -9V$



$D_1 = OFF$, $D_2 = ON$

$i_{D_1} = 0$, $V_{D_2} = 0$

KVL (CCW)

$v_{in} + \cancel{V_{D_2}}^{0} + 9V + i_{D_2}(2k\Omega) = 0$

$$i_{D_2} = \frac{-v_{in} - 9V}{2}$$

$i_{D_2} > 0$ as long as $v_{in} < -9V$ ✓

KVL (Middle, CW)

$$-6V - v_{D_1} - 9V - v_{D_2} = 0 \quad (v_{D_2} \to 0)$$

$$\boxed{v_{D_1} = -15V < 0}$$

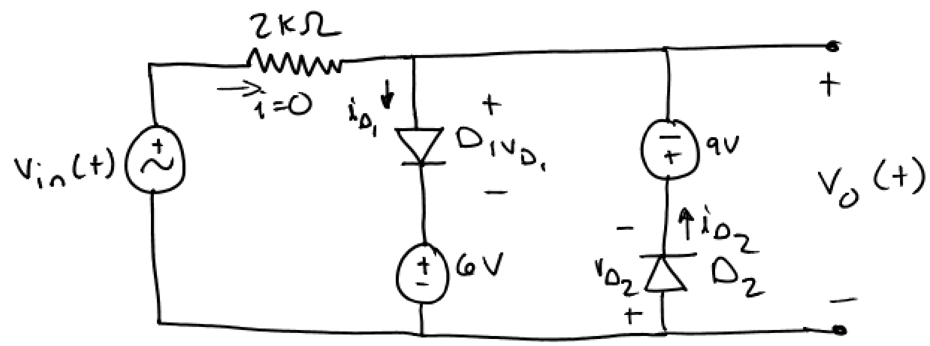
$D_1 = OFF,\ D_2 = ON$ for $-15V < v_{in} < -9V$

KVL (Right, CW)

$$v_{D_2} + 9V + v_o = 0 \quad (v_{D_2} \to 0)$$

$$\boxed{v_o = -9V}$$

$-9V < v_{in} < 6V$



$D_1 = OFF,\ D_2 = OFF$

$i_{D_1} = 0 \qquad i_{D_2} = 0$

KVL (Left, CW)

$$-v_{in} + v_{D_1} + 6V = 0$$

$$\boxed{v_{D_1} = v_{in} - 6V}$$

$v_{D_1} < 0$ for $v_{in} < 6V$

KVL (Left Two Loops, cw)

$$-v_{in} - 9V - v_{D_2} = 0$$

$$v_{D_2} = -v_{in} - 9V$$

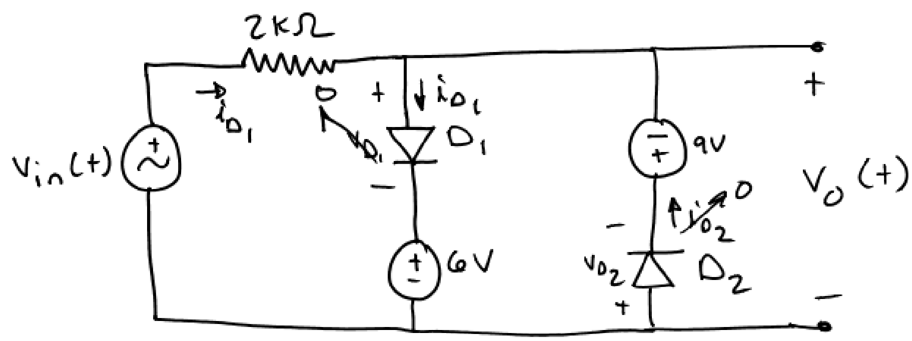
$$v_{D_2} < 0 \quad \text{for} \quad v_{in} > -9V$$

$D_1 = OFF$, $D_2 = OFF$

KVL (Perimeter, cw)

$$-v_{in} + v_o = 0 \qquad v_o = v_{in}$$

$6V < v_{in} < 15V$



$D_1 = ON$, $D_2 = OFF$

$v_{D_1} = 0 \qquad i_{D_2} = 0$

KVL (Left, cw)

$$-v_{in} + i_{D_1}(2k\Omega) + 6V = 0$$

$$i_{D_1} = \frac{v_{in} - 6V}{2}$$

$$i_{D_1} > 0 \quad \text{for} \quad v_{in} > 6V$$

KVL (Middle, CW)

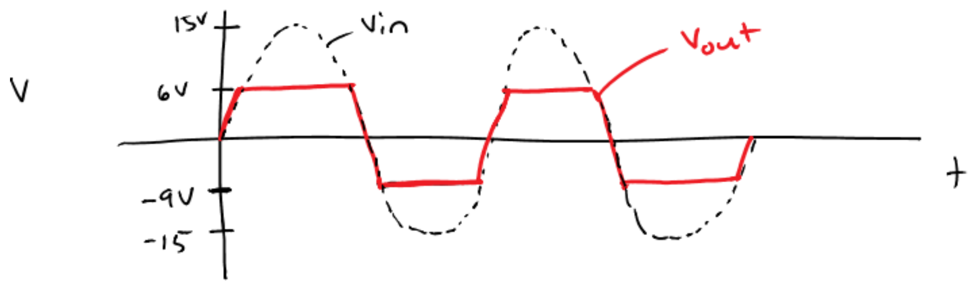
$$-6V - 9V - V_{D_2} = 0$$

$$V_{D_2} = -15V < 0 \quad \checkmark$$

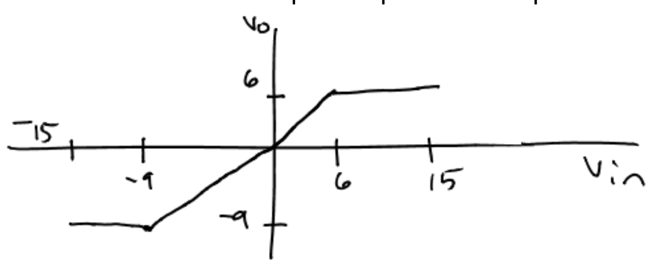
$$D_1 = ON, \; D_2 = OFF$$

KVL (Right Two Loops, CW)

$$-6V + V_o = 0 \qquad \boxed{V_o = 6V}$$

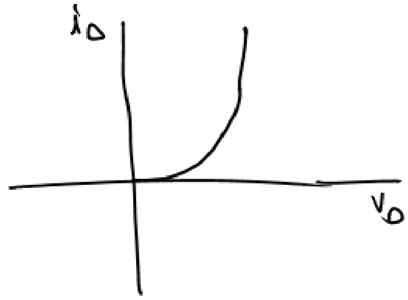


- Transfer Function: Graphs output versus input



Shockley Equation

- Provides the current versus voltage characteristic equation for a pn-junction (diode) in the Forward Bias Region



$$i_D = I_S\left[e^{\left(\frac{v_D}{nV_T}\right)} - 1\right]$$

I_S = Saturation Current in order of 10^{-14} A for small-signal diodes at 300 K

n = Emission Coefficient

$1 < n < 2$

V_T = Thermal Voltage

$= \frac{kT}{q}$

k = Boltzmann's Constant $= 1.38 \times 10^{-23}$ J/K

T = Temperature

q = Electron Charge $= 1.6 \times 10^{-19}$ Coulombs