Basic Electronics

-Ste Kulov

Electricity is the act of moving particles with a negative charge from one place to another. These particles are called electrons:

Electron charge $Q_e = -0.16 \times 10^{-18}$ C

C = Coulombs

Potential difference is the potential energy required to move 1 Coulomb of charge:

$$PD = \frac{PE}{Q} \Longrightarrow \text{Volts} = \frac{\text{Joules}}{\text{Coulombs}}$$

Current is charge in motion:

$$I = \frac{Q}{T} \Longrightarrow \text{Amps} = \frac{\text{Coulombs}}{\text{seconds}}$$

Resistance is opposition to current. Heat is generated due to this opposition.

R = resistance $\qquad \Omega$ = ohms

Conduction is the opposite (inverse) of resistance

$$G = \text{conductance} \Longrightarrow G = \frac{1}{R} \Longleftrightarrow R = \frac{1}{G}$$

$$\text{Siemens} = \frac{1}{\text{Ohms}} \quad \text{or} \quad S = \frac{1}{\Omega}$$

$$\text{mhos} = \mho = \frac{1}{\Omega}$$

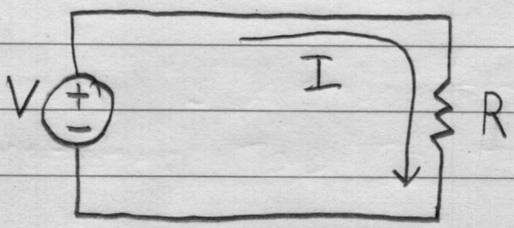
Conductors (wires): Silver, Copper, Gold, Aluminum
$R \to 0$

Isulators: Foam, Wood, Plastic, Paper
$R \to \infty$

Semiconductors: (Periodic Table) Silicon, Germanium, Carbon

Simplest Circuit

Conventional vs. Electron Flow



R = load resistance

$R = 0 \Rightarrow$ short circuit

$R = \infty \Rightarrow$ open circuit

"Heavy Load" $\Rightarrow$ low R & high I

"Light Load" $\Rightarrow$ high R & low I

DC: Direct current
Result of constant V
Ex: is a battery

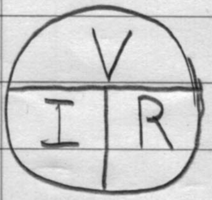
AC: Alternating Current
reverses polarity
usually a sine wave (Hz
Ex: power outlet in house.

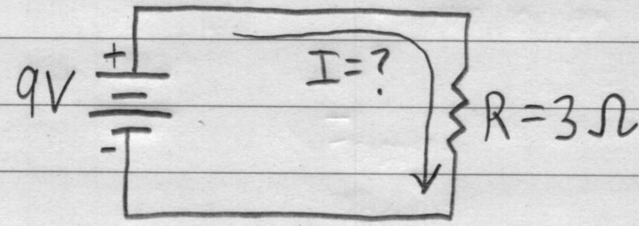
Ohm's Law

$V = IR$

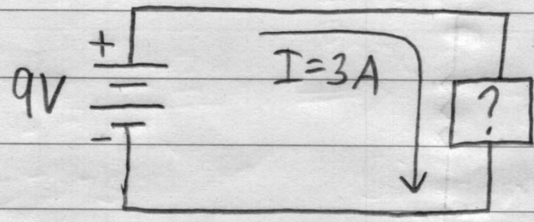
volts = amps × ohms

$I = \frac{V}{R}$ $\quad R = \frac{V}{I}$

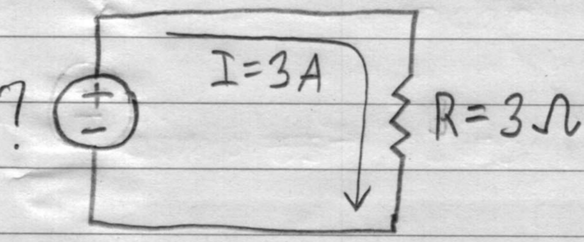




$I = \frac{9V}{3\Omega} = 3A$



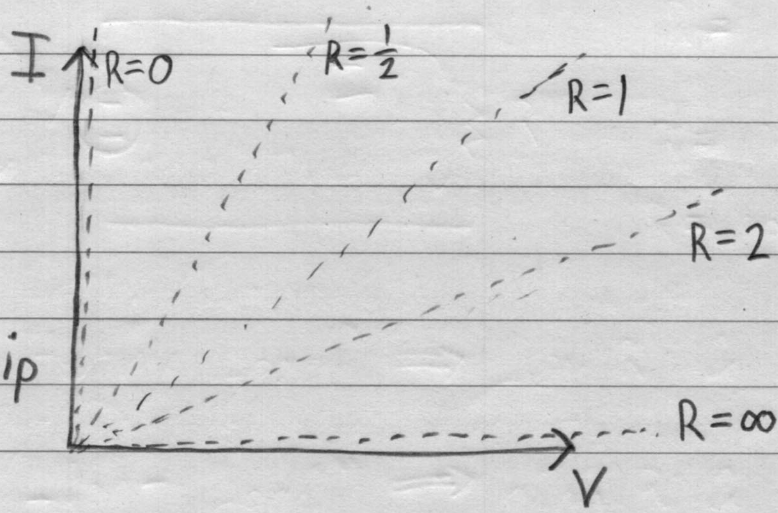
$R = \frac{9}{3} = 3\Omega$



$V = 3 \cdot 3 = 9V$

I-V Curve

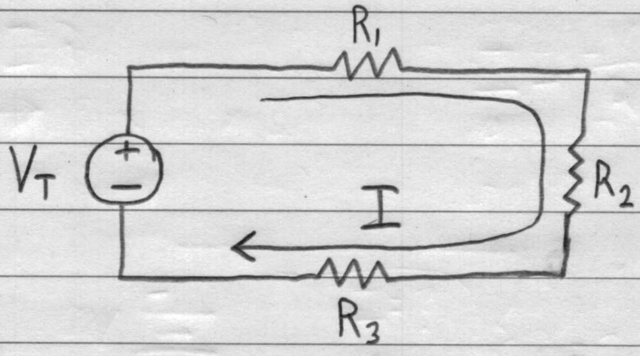
Linear Relationship



<u>Power:</u> Power = Voltage × Current $\quad P = V \cdot I$

$P = \frac{V^2}{R}$ $\quad P = I^2 R$ $\quad \text{Watts} = \frac{\text{Joules}}{\text{second}} \Longleftrightarrow W = \frac{J}{s}$

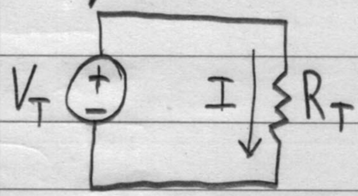
Series Circuits



Equivalent Circuit

$R_T = R_1 + R_2 + R_3$

$I = \dfrac{V_T}{R_T}$



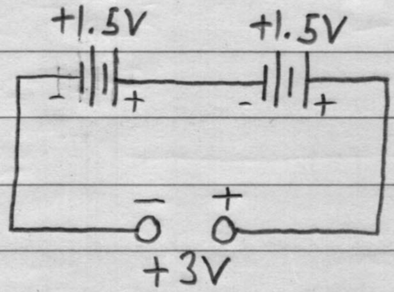
$V_1 = R_1 \cdot I$
$V_2 = R_2 \cdot I$
$V_3 = R_3 \cdot I$
(Voltage Drop)

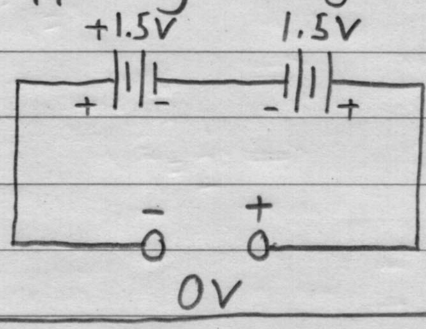
Kirchoff's Voltage Law (KVL): $V_T - V_1 - V_2 - V_3 = 0$

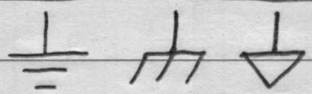
$\Rightarrow V_T = V_1 + V_2 + V_3$

$P_T = P_1 + P_2 + P_3 = V_T \cdot I$

Series aiding/opposing voltages

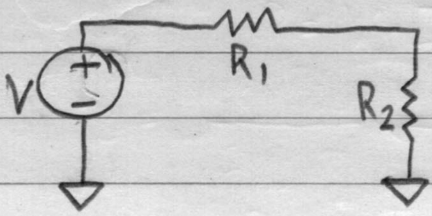




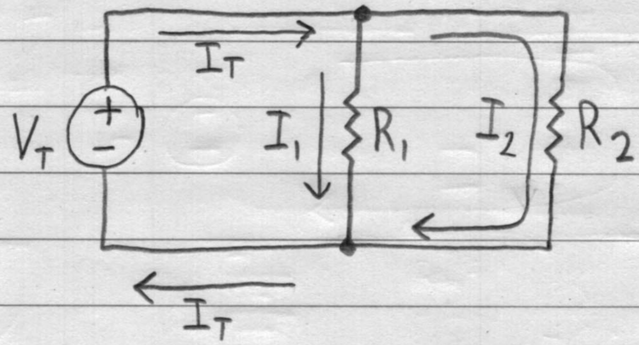
 Grounds (common return path)

Voltages are usually measured with respect to ground

Ground is considered to be at zero potential



Parallel Circuits

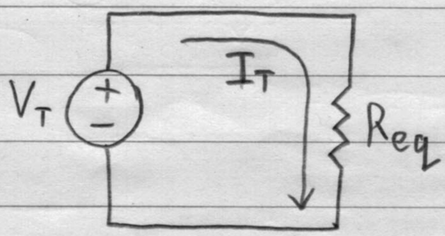


$V_T = R_1 I_1$

$V_T = R_2 I_2$

Kirchoff's Current Law: $I_T = I_1 + I_2$
(KCL)

$V_T = R_{eq} I_T$



$$\frac{V_T}{R_{eq}} = I_T$$

$$\frac{V_T}{R_{eq}} = I_1 + I_2 = \frac{V_T}{R_1} + \frac{V_T}{R_2}$$

$$V_T\left(\frac{1}{R_{eq}}\right) = V_T\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

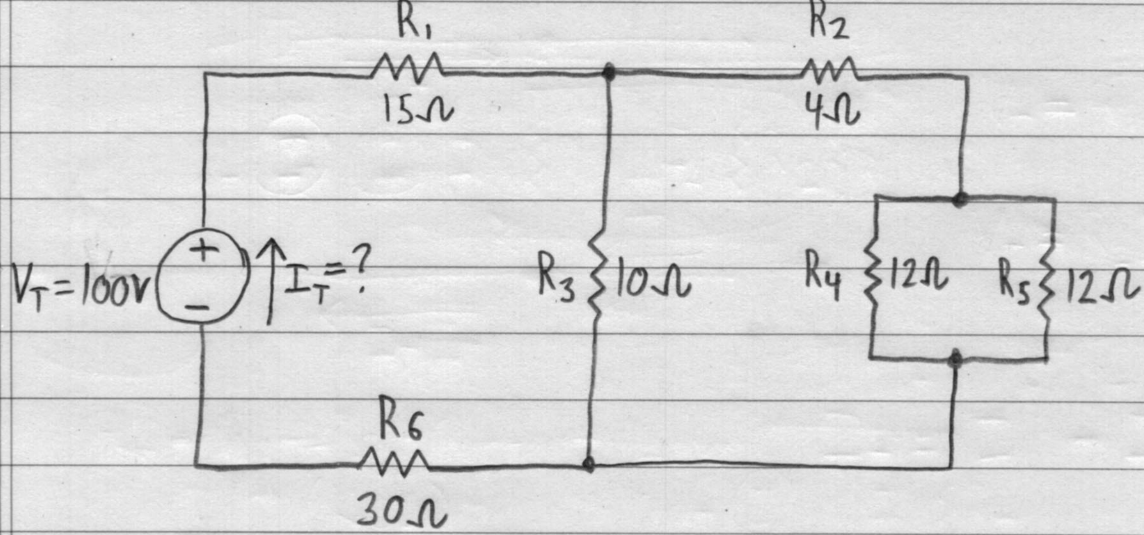
$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{R_1 R_2}{R_1 + R_2}$$

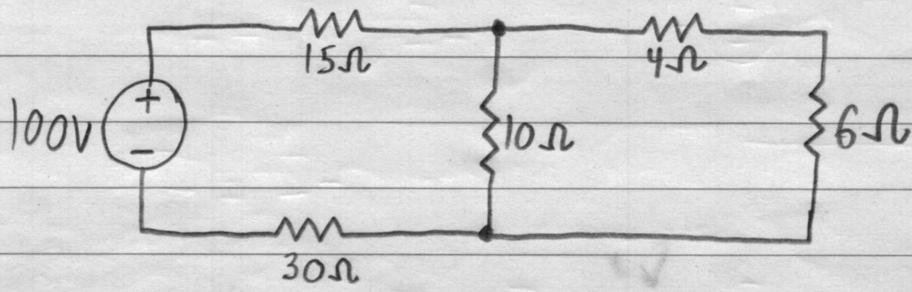
R_{eq} is always less than the lowest separate resistanc

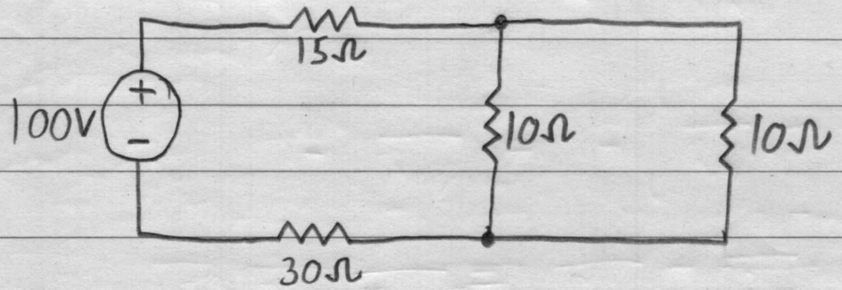
Special case when $R_1 = R_2 = R \Rightarrow \frac{R^2}{2R} = \frac{R}{2} = R_{eq}$

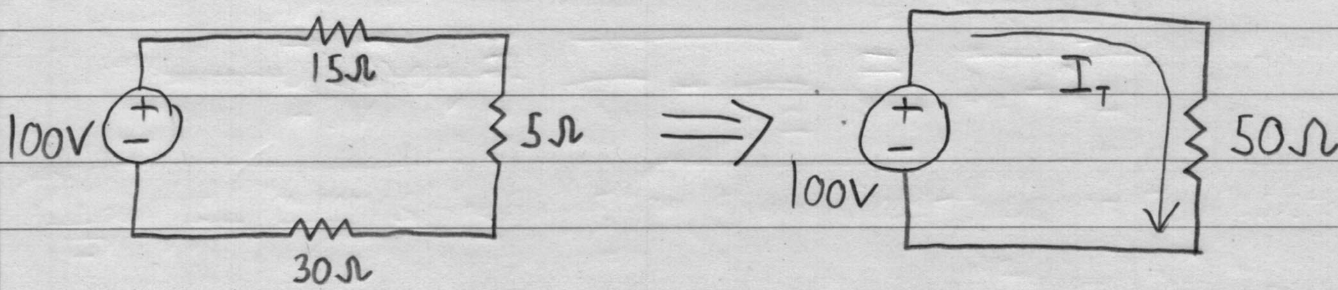
$P_T = P_1 + P_2 = V_T \cdot I_T$

Circuit Reduction





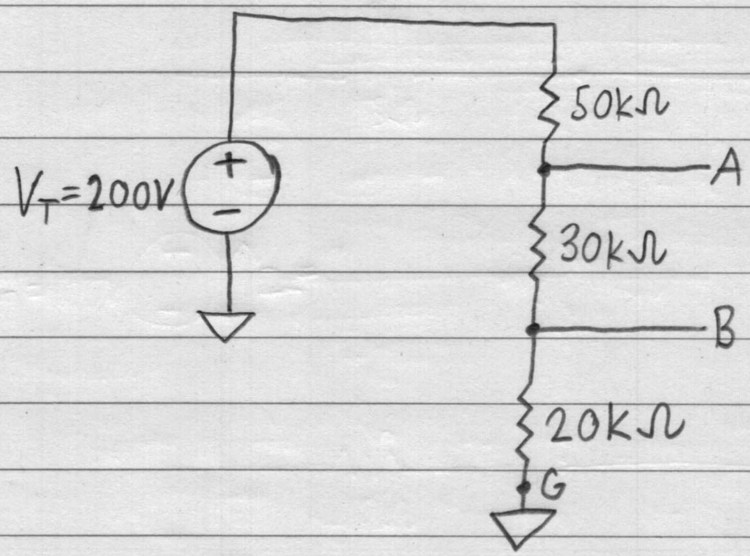




$$I_T = \frac{100V}{50\Omega} = 2A$$

$$P_T = 100V \cdot 2A = 200W$$

Voltage Divider



$$V = V_T \cdot \frac{R}{R_T}$$

Series circuit so $R_T = 50 + 30 + 20$
$= 100k\Omega$

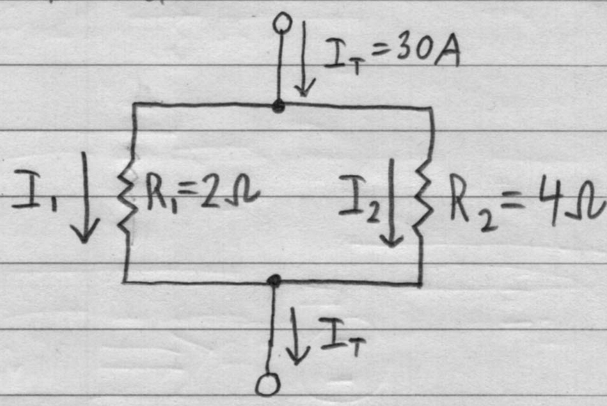
A & B are "voltage taps" with respect to G.

$$V_A = V_T \cdot \frac{R_A}{R_T} = 200 \cdot \frac{30+20}{100} = 100V$$

$$V_B = V_T \cdot \frac{R_B}{R_T} = 200 \cdot \frac{20}{100} = 40V$$

Current Divider

$$I = I_T \cdot \frac{G}{G_T}$$



$$G_1 = \frac{1}{R_1} = \frac{1}{2} S$$

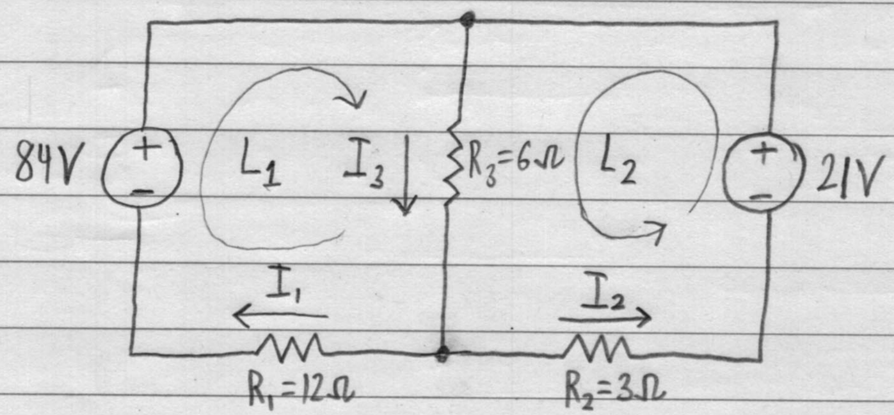
$$G_2 = \frac{1}{R_2} = \frac{1}{4} S$$

$$G_T = G_1 + G_2 = \frac{1}{2} + \frac{1}{4} = \frac{2}{4} + \frac{1}{4} = \frac{3}{4} \mho$$

$$I_1 = I_T \cdot \frac{G_1}{G_T} = 30 \cdot \frac{\frac{1}{2}}{\frac{3}{4}} = 30 \cdot \frac{1}{2} \cdot \frac{4}{3} = 30 \cdot \frac{2}{3} = 20A$$

$$I_2 = I_T \cdot \frac{G_2}{G_T} = 30 \cdot \frac{\frac{1}{4}}{\frac{3}{4}} = 30 \cdot \frac{1}{4} \cdot \frac{4}{3} = 30 \cdot \frac{1}{3} = 10A$$

Branch Currents
(straight KVL/KCL)



KVL

L_1: $84 - V_{R3} - V_{R1} = 0 \Rightarrow 84 - I_3R_3 - I_1R_1 = 0$

$84 - 6I_3 - 12I_1 = 0$

L_2: $21 - V_{R3} - V_{R2} = 0 \Rightarrow 21 - I_3R_3 - I_2R_2 = 0$

$21 - 6I_3 - 3I_2 = 0$

KCL

$I_3 = I_1 + I_2 \xrightarrow{L_1} 84 - 6(I_1 + I_2) - 12I_1 = 0$

$84 - 6I_1 - 6I_2 - 12I_1 = 0$

$84 - 18I_1 - 6I_2 = 0$

$18I_1 + 6I_2 = 84$

$3I_1 + I_2 = 14$

$\downarrow L_2$

$21 - 6(I_1 + I_2) - 3I_2 = 0$

$21 - 6I_1 - 6I_2 - 3I_2 = 0$

$21 - 6I_1 - 9I_2 = 0$

$6I_1 + 9I_2 = 21$

$2I_1 + 3I_2 = 7$

$3I_1 + I_2 = 14$

$2I_1 + 3I_2 = 7$

$-9I_1 - 3I_2 = -42$

$2I_1 + 3I_2 = 7$

$-7I_1 = -35$

$I_1 = 5A$

$15 + I_2 = 14$

$I_2 = -1A$ (Flip Arrow)

$I_3 = 5 - 1 = 4A$

$V_{R1} = I_1 R_1 = 5 \cdot 12 = 60V$
$V_{R2} = I_2 R_2 = 1 \cdot 3 = 3V$
$V_{R3} = I_3 R_3 = 4 \cdot 6 = 24V$

L1: $84 - 60 - 24 = 0V$ ✓
L2: $21 + 3 - 24 = 0V$ ✓

Node Voltage

$$I_1 + I_2 = I_3$$

$$\Rightarrow \frac{V_{R1}}{R_1} + \frac{V_{R2}}{R_2} = \frac{V_N}{R_3}$$

$$\Rightarrow \frac{V_{R1}}{12} + \frac{V_{R2}}{3} = \frac{V_N}{6}$$

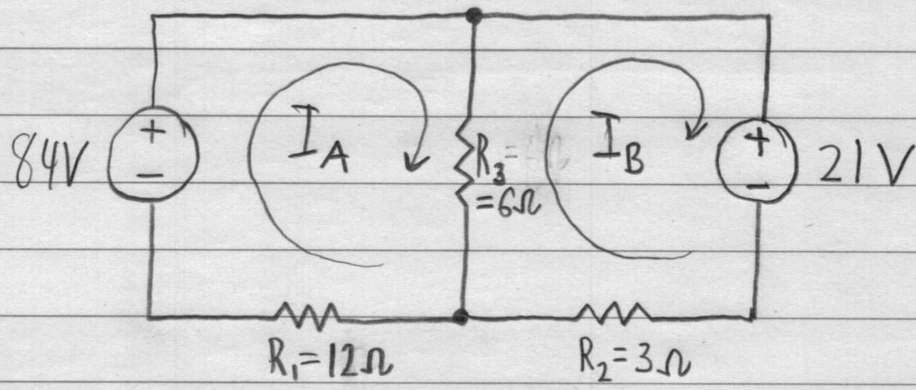
$$84 - V_{R1} - V_N = 0 \Rightarrow V_{R1} = 84 - V_N$$

$$21 - V_{R2} - V_N = 0 \Rightarrow V_{R2} = 21 - V_N$$

$$\frac{84 - V_N}{12} + \frac{21 - V_N}{3} = \frac{V_N}{6}$$

$$84 - V_N + 4(21 - V_N) = 2V_N$$
$$84 - V_N + 84 - 4V_N = 2V_N$$
$$168 - 5V_N = 2V_N$$
$$168 = 7V_N \Rightarrow V_N = 24$$
$$V_{R1} = 84 - V_N \Rightarrow V_{R1} = 84 - 24 = 60V$$
$$V_{R2} = 21 - V_N \Rightarrow V_{R2} = 21 - 24 = -3V$$ (Flip Arrow)

Mesh Currents



(pick a direction and be consistent) → Clockwise

$L_A: 84 - 6I_A - 12I_A + 6I_B = 0$

$84 - 18I_A + 6I_B = 0$

$18I_A - 6I_B = 84$

$3I_A - I_B = 14$

$3I_A - I_B = 14$

$2I_A - 3I_B = 7$

$L_B: -21 - 3I_B - 6I_B + 6I_A = 0$

$-21 - 9I_B + 6I_A = 0$

$6I_A - 9I_B = 21$

$2I_A - 3I_B = 21$

$$\begin{array}{r} -9I_A + 3I_B = -42 \\ 2I_A - 3I_B = 7 \\ \hline -7I_A = -35 \end{array}$$

$I_A = 5A$

$2 \cdot 5 - 3I_B = 7$

$-3I_B = -3$

$I_B = 1A$

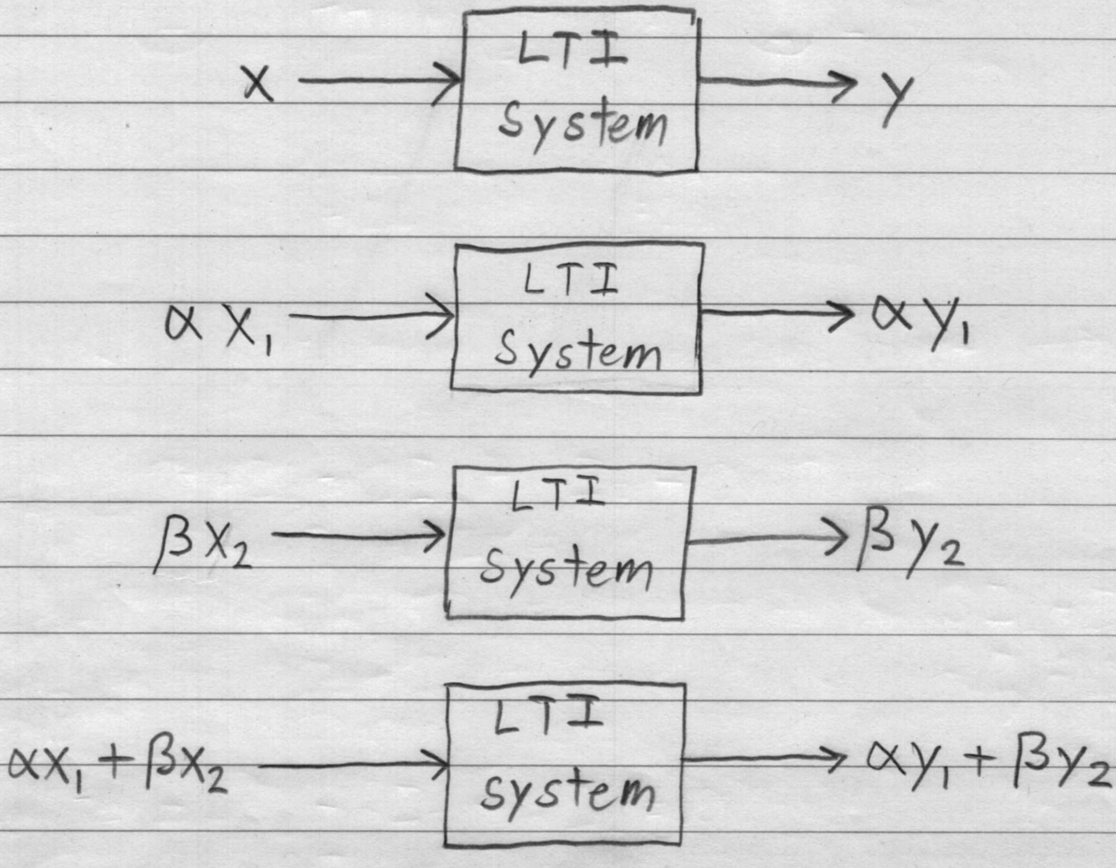
$I_{R1} = I_A = 5A$

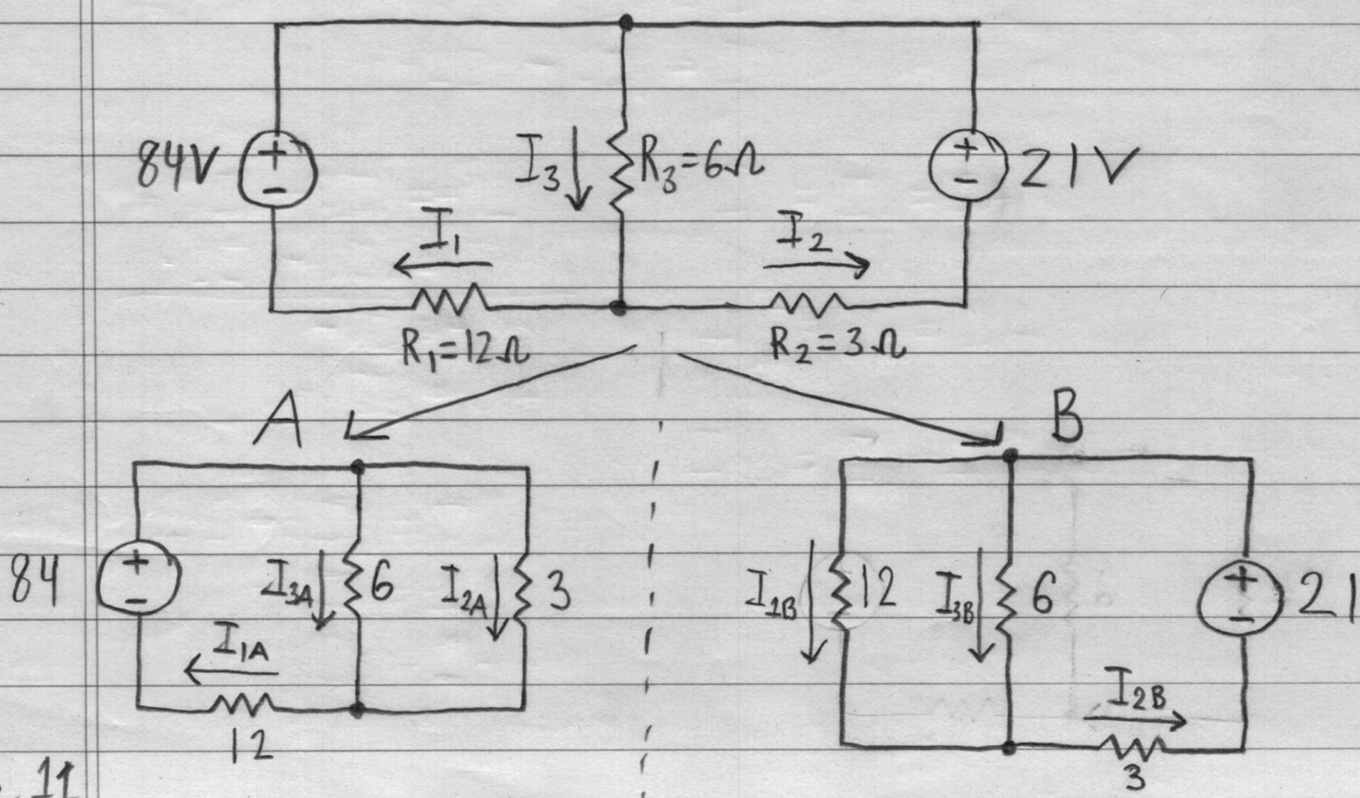
$I_{R2} = I_B = 1A$

$I_{R3} = I_A - I_B = 5 - 1 = 4A$

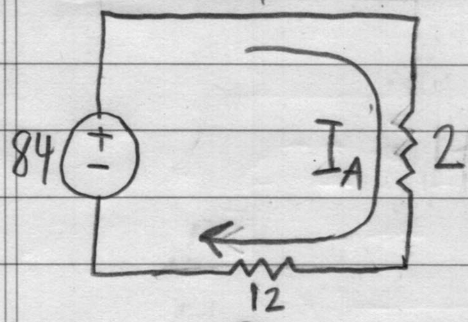
Superposition
(Linearity)

LTI = Linear Time Invarient

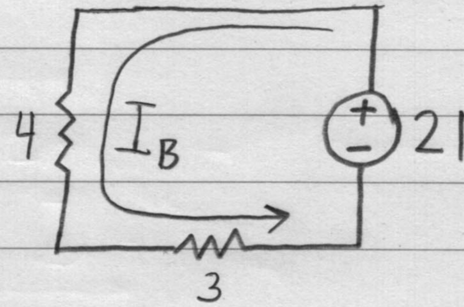




A



B



$I_A = \frac{84}{12+2} = 6$

$V_a = 2 \cdot 6 = 12$

~~$V_b = 12 \cdot 6 = 72$~~

$I_{1A} = I_A = 6A$

$I_{2A} = \frac{12}{3} = 4A$

$I_{3A} = \frac{12}{6} = 2A$

$I_B = \frac{21}{4+3} = 3$

$V_b = 4 \cdot 3 = 12$

~~$V_d = 3 \cdot 3 = 9$~~

$I_{1B} = \frac{12}{12} = 1A$

$I_{2B} = I_B = 3A$

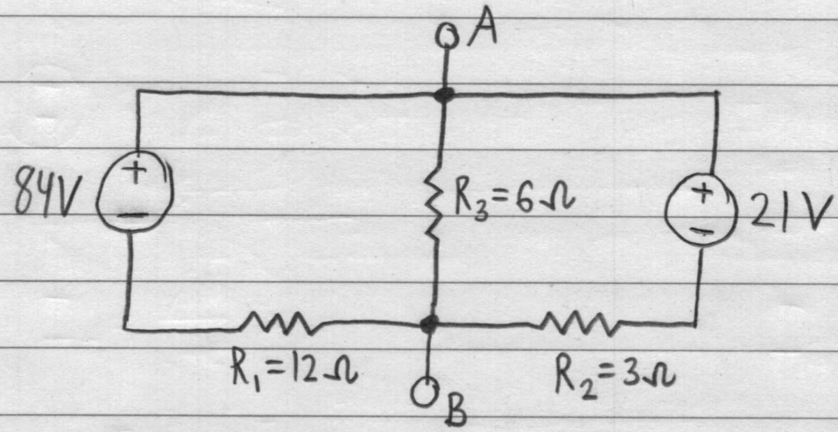
$I_{3B} = \frac{12}{6} = 2A$

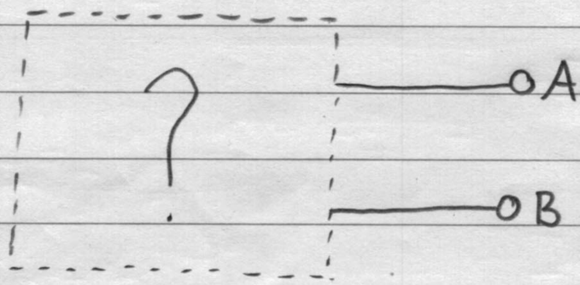
$I_1 = I_{1A} - I_{1B} = 6 - 1 = 5A$

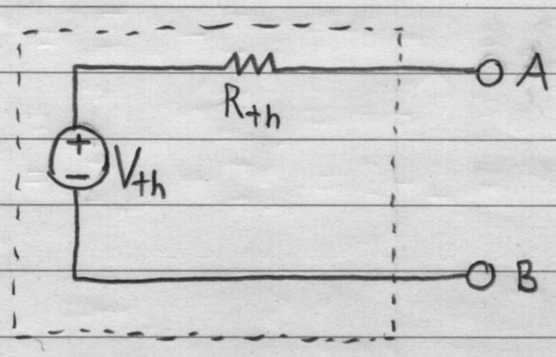
$I_2 = I_{2A} - I_{2B} = 4 - 3 = 1A$

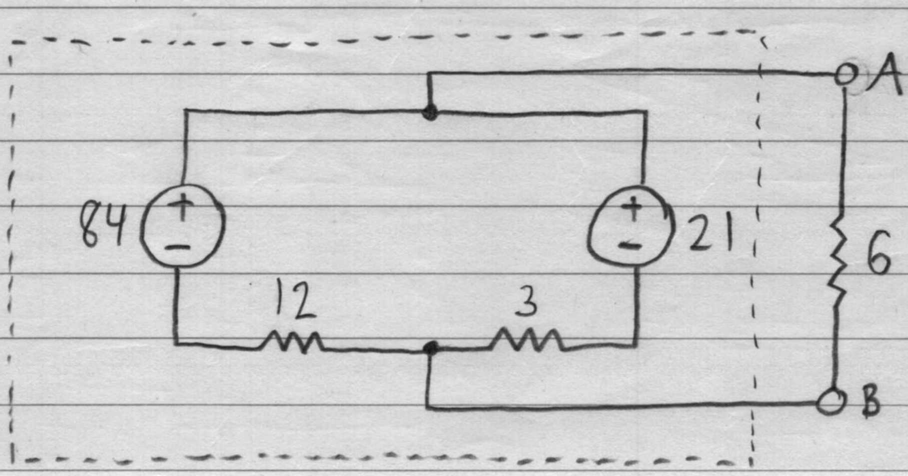
$I_3 = I_{3A} + I_{3B} = 2 + 2 = 4A$

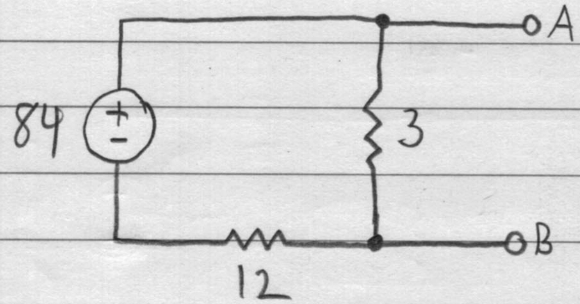
Thevenin`s Theorem





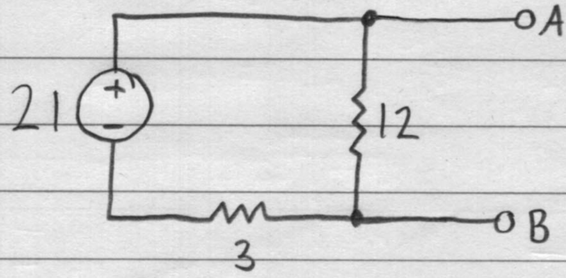






$$V_B = 84 \cdot \frac{12}{15} = 67.2$$

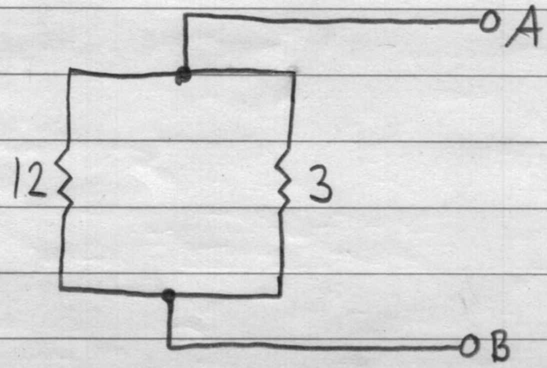
$$V_{AB} = 84 - 67.2 = 16.8V$$



$$V_B = 21 \cdot \frac{3}{15} = 4.2$$

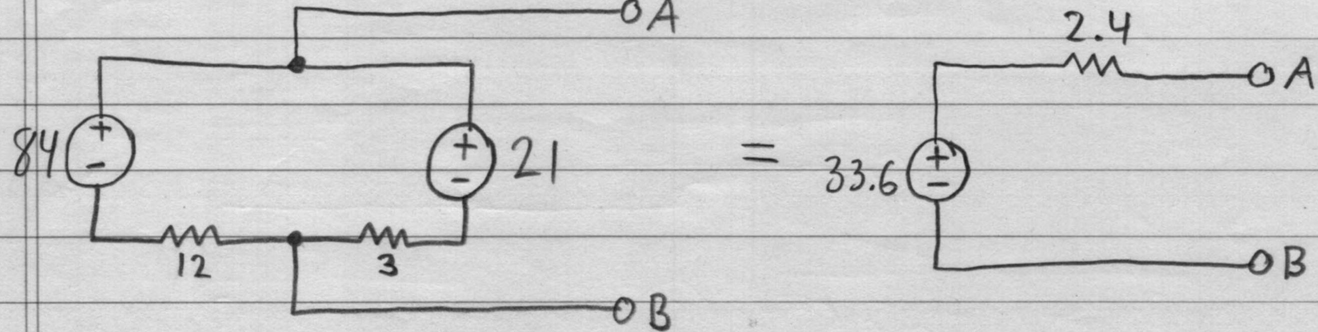
$$V_{AB} = 21 - 4.2 = 16.8V$$

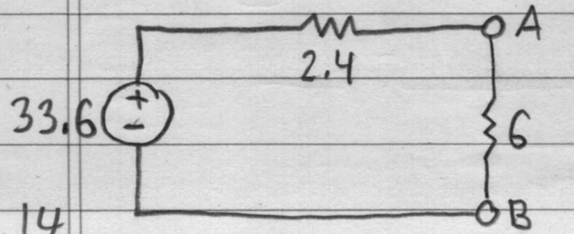
$$V_{th} = 16.8 + 16.8 = 33.6$$



$$R_{th} = 12 \| 3$$

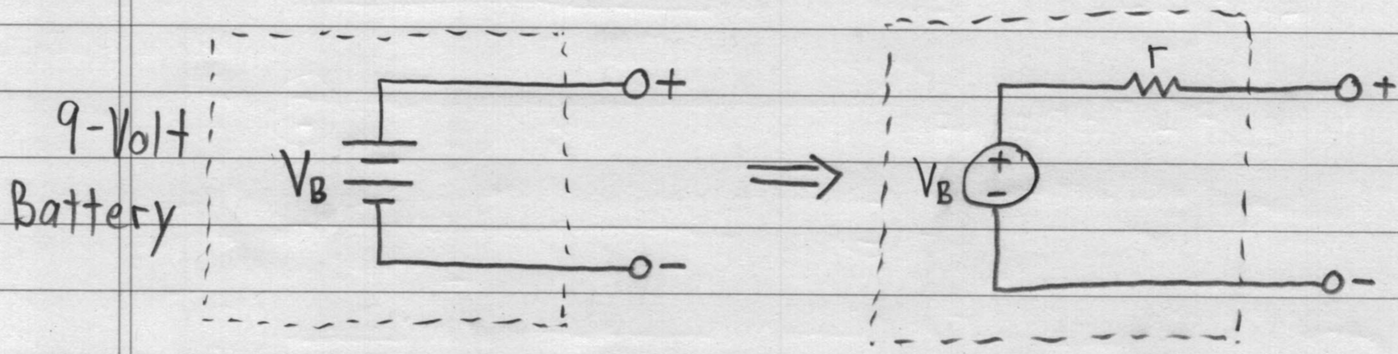
$$= \frac{12 \cdot 3}{12+3} = \frac{36}{15} = 2.4$$



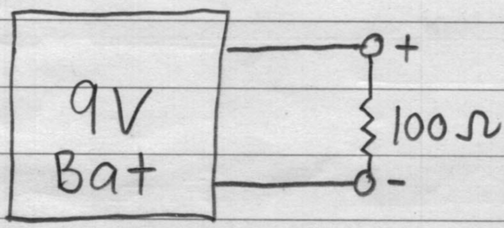


$$V_{AB} = 33.6 \cdot \frac{6}{8.4} = 24V$$

Real Batteries

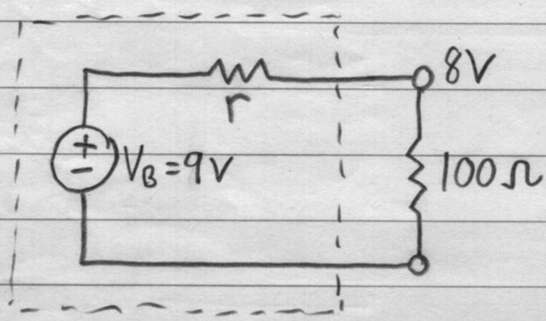


Measure and get $V_B = 9V$



Attach load.

Measure now and get 8V



Find r:

$$8 = 9 \cdot \frac{100}{r+100}$$

$$8r + 800 = 900$$

$$8r = 100$$

$$r = 12.5\Omega$$

r is not constant. Weaker battery has a higher r. Heavier load results in higher r.

Diodes

Diodes are the basic semiconductor device

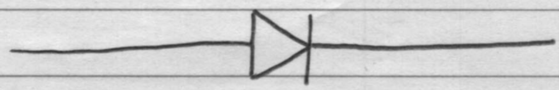
Semiconductor means that under certain conditions it will conduct and under other conditions it will not conduct (insulate).

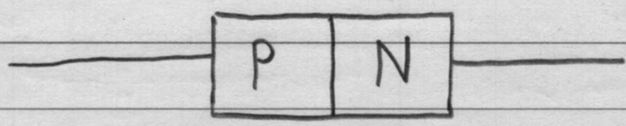
Silicon is the most common.
Germanium used to be used frequently.
Gallium / Arsenic are used in light-emitting diodes (LEDs)
(4 valence electrons)

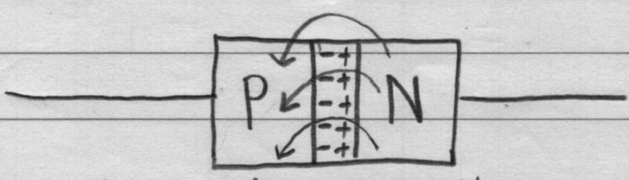
PN junction: Pure silicon is "doped" with impurities

p-type silicon: 3 valence electrons (Al)

n-type silicon: 5 valence electrons (P)







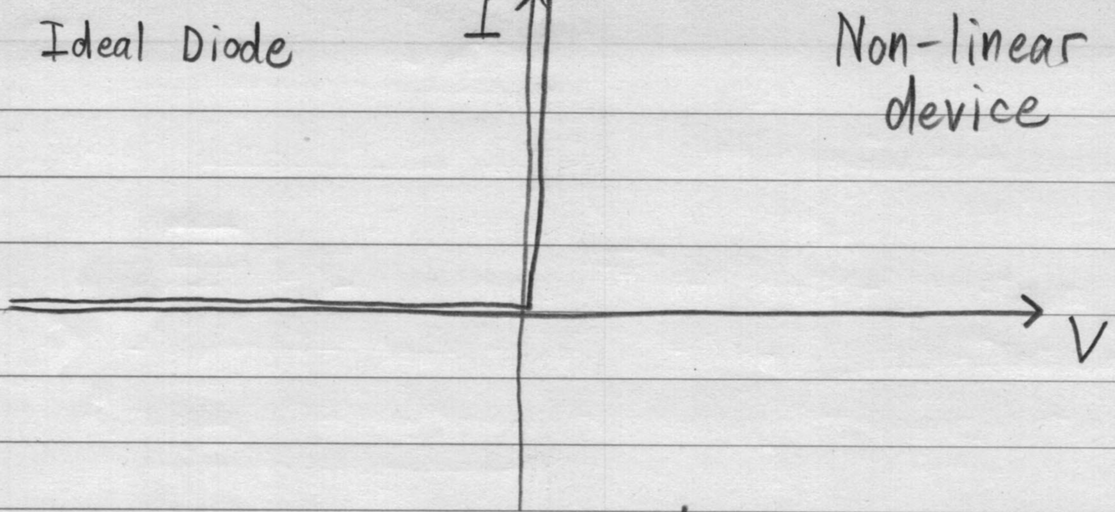
electrons jump over the depletion region

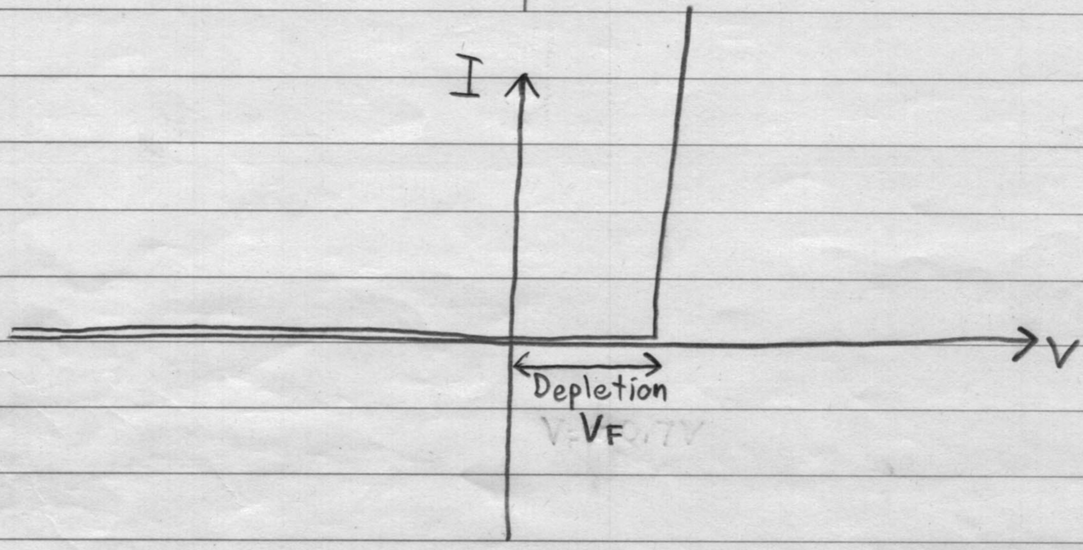
Diode equation: $I = I_0\left(e^{\frac{qV}{nkT}} - 1\right)$ $\quad 1 \le n \le 2$

$\frac{kT}{q} = V_T$ @ 300K (room Temp), $V_T \approx 26mV$ $\quad \therefore I = I_0\left(e^{\frac{V}{0.026n}} - 1\right)$

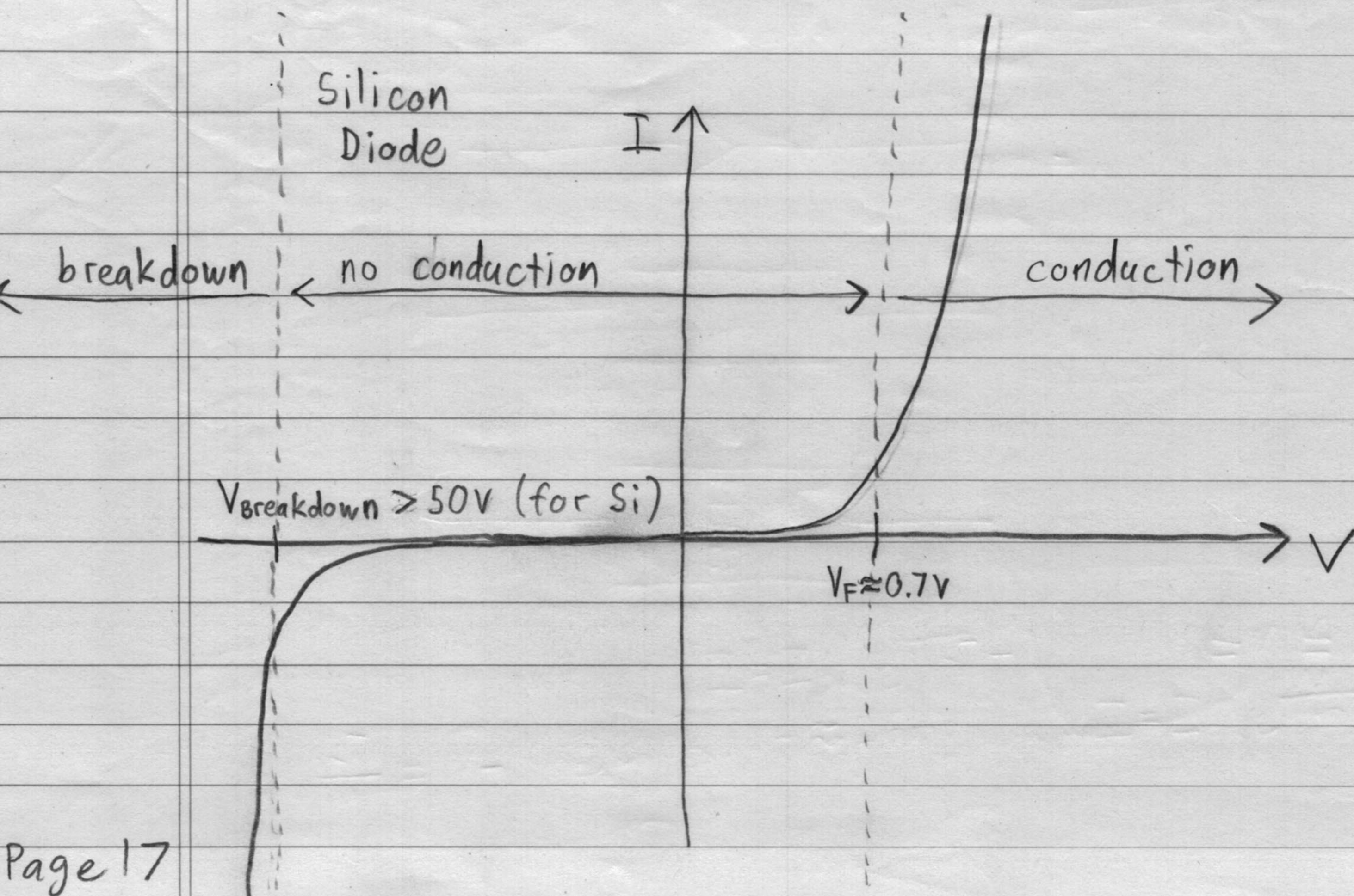
Ideal Diode

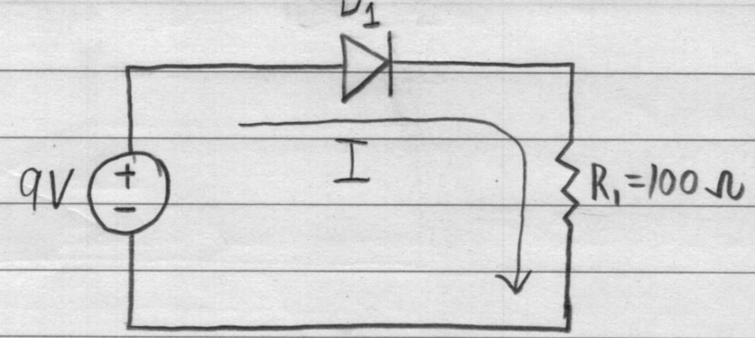
Non-linear device





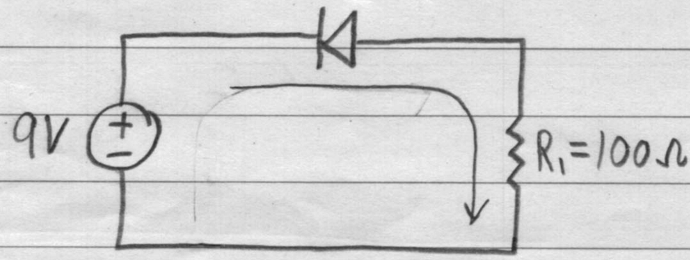
Silicon Diode





Forward Biased

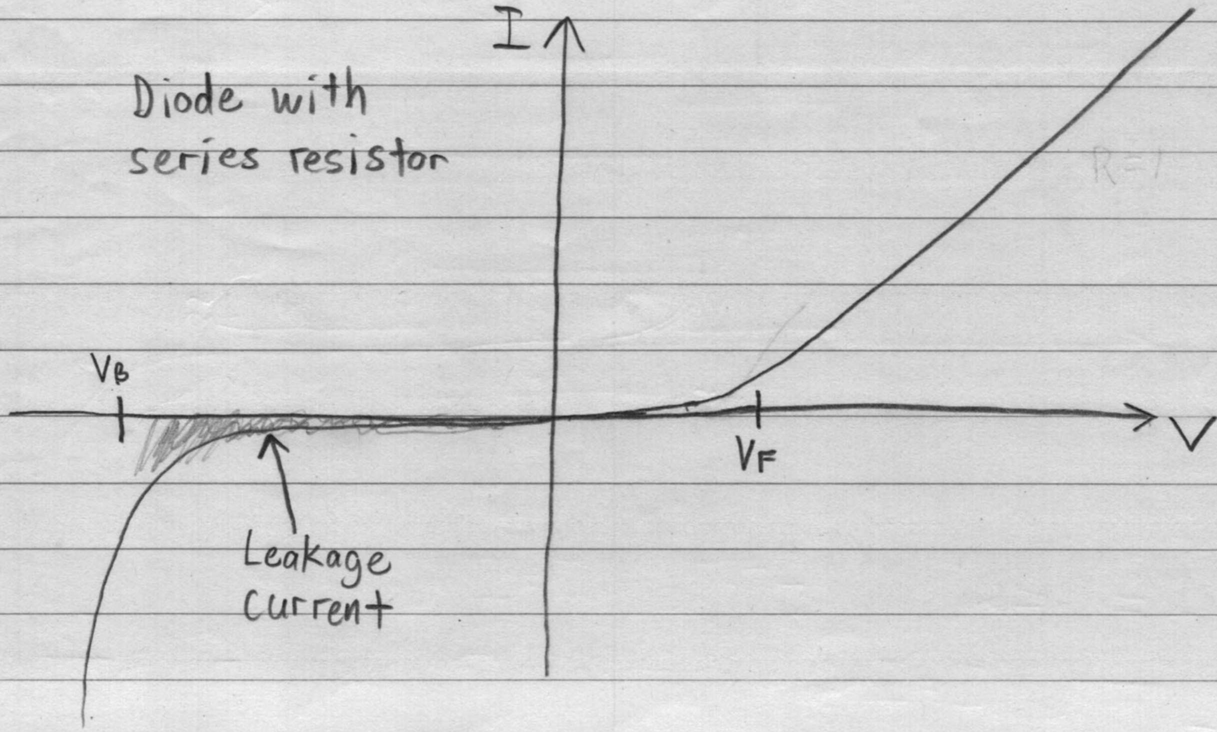
$$I = \frac{V_{R1}}{R_1} = \frac{9-0.7}{100} = \frac{8.3}{100} = 0.083A = 83mA$$

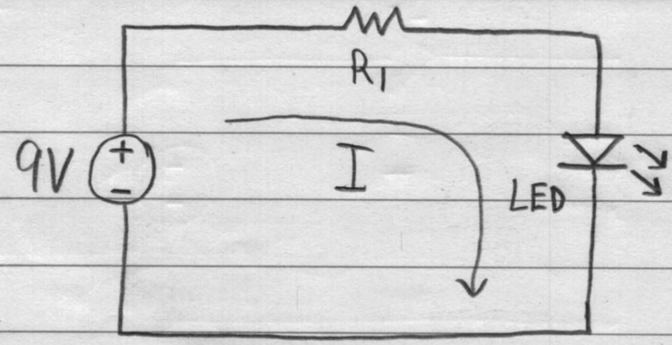


Reverse Biased

$$I = \frac{V_{R1}}{R_1} = \frac{0}{100} = 0A$$

Diodes have a spec called "leakage current" which is the small amount of current the diode conducts in reverse bias.





V_F for LEDs depends on the size and color. For basic red, green, and yellow LEDs: $V_F \approx 2.0V$ (see datasheet)

What should R_1 be such that 100mA flows through the LED ($I = 100mA$)

KVL: $9 - V_{R_1} - V_F = 0$

$$9 - 2.0 = V_{R_1}$$

$$V_{R_1} = 7$$

$$I = \frac{V_{R1}}{R_1}$$

$$0.1 = \frac{7}{R_1}$$

$$0.1R_1 = 7$$

$$R_1 = 70\Omega$$

LTspice

1.) Voltage Divider Circuit
2.) Analysis Circuit
3.) Thevenin Circuit
4.) Forward Diode Circuit
5.) Reverse Diode Circuit
6.) LED circuit