ECE110 *Introduction to Electronics*

What is...?

ECE

ECE110

Charge

Current

Voltage

Power

Energy

Kirchhoff's Current Law

① $Q_{in} = Q_{out}$ $/ \frac{1}{\Delta t}$

$\frac{Q_{in}}{\Delta t} = \frac{Q_{out}}{\Delta t}$

$I_{in} = I_{out}$

Current in = Current out

Conservation of charge!

(What goes in must come out, or…

…the total coming in is zero)

1,000,000 gallons/A.sec

I_{in}

e

e

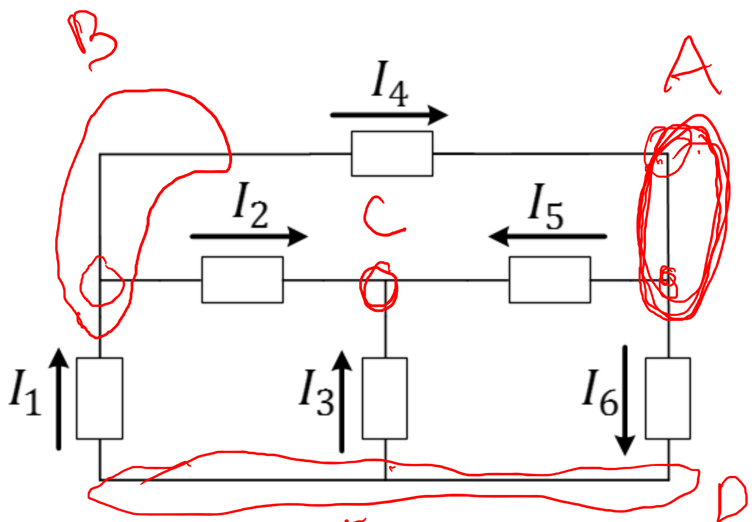
Image source: MONGABAY.COM

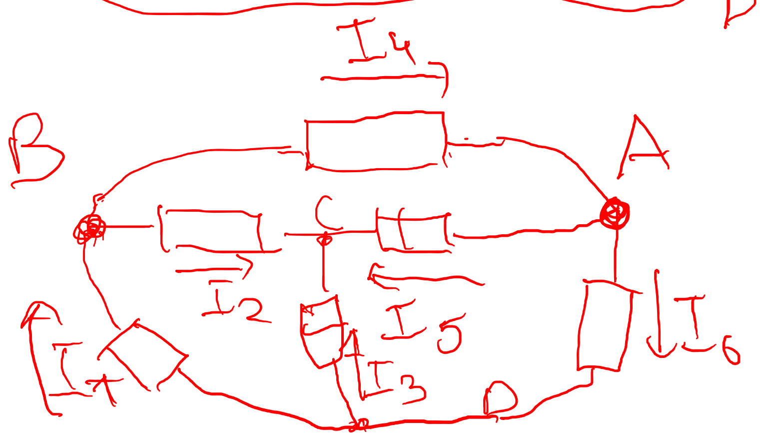
I_{out}

100%

$$Through\ a\ closed\ surface\ (balloon),\ \sum_{k=1}^{N} I_k = 0\ where\ I_k\ are\ the\ currents\ flowing\ in\ (alt.out)\ of\ the\ balloon.$$

KCL equations are often used at *nodes*, but can also be used for a *sub-circuit*





L5Q1: Which of the equations is NOT a correct application of KCL?

A. $I_1 = I_2 + I_4$ ✓
B. $I_4 = I_5 + I_6$ ✓
C. $I_1 + I_3 = I_6$ ✓
D. $I_3 + I_5 = I_2$
E. $I_6 - I_4 = I_3 + I_2$ ✓

$\boxed{\text{node A}}$

$I_4 = I_5 + I_6$

$\boxed{\text{node B}}$

$I_1 = I_2 + I_4$ ✓

$\boxed{\text{node C}}$

$I_2 + I_5 + I_3 = 0$

$\boxed{\text{node D}}$

$I_6 = I_1 + I_3$ ✓

$I_6 = I_2 + I_4 + I_3 \Rightarrow I_6 - I_4 = I_3 + I_2$

Kirchhoff's Voltage Law

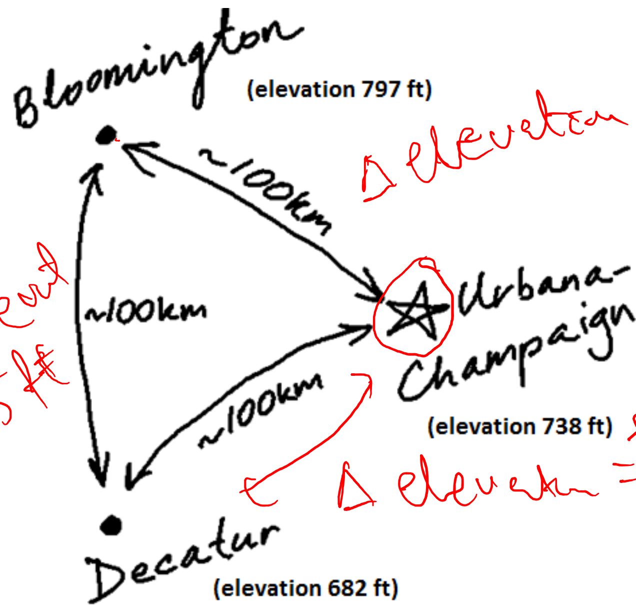
The sum of all voltages around any closed path (loop) in a circuit equals zero

Conservation of Energy!

With voltage, what goes up, must come down

$$\textit{Around a closed loop (path)} \sum_{k=1}^{M} V_k = 0 \quad \textit{where } V_k \textit{ are the voltages measured } CW\,(alt.\,CCW) \textit{ in the loop.}$$

KVL and Elevation Analogy



Δ elevation $= +59$ ft

Δ elevat $= -115$ ft

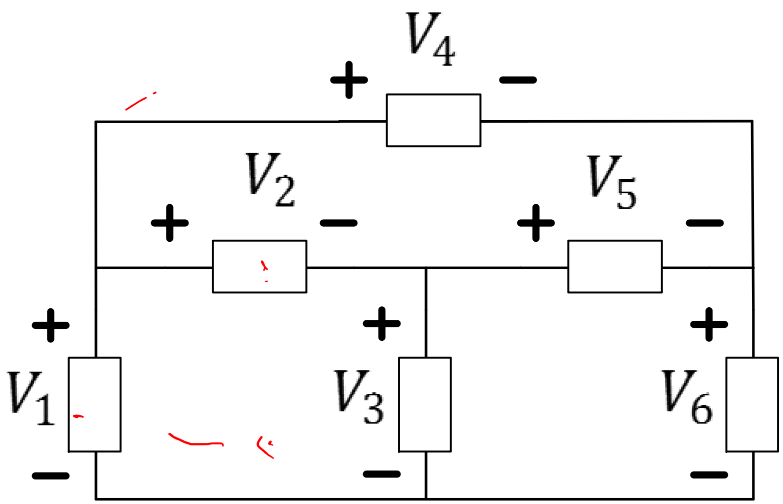
Δ elevation $= +56$ ft

$(+59\text{ ft}) + (-115\text{ ft}) + (56\text{ ft}) = 0$

Free Picture: Stairs To The Sky ID: 191634

One can add up elevation changes as we go in a loop from city to city.
The result should be zero, independent of the path taken.

Keeping track of voltage drop *polarity* is important in writing correct KVL equations.



L5Q2: Which of the equations is NOT a correct application of KVL?

A. $V_1 - V_2 - V_3 = 0$ ✓
B. $V_1 = V_2 + V_5 + V_6$ ✓
C. $V_1 - V_4 = V_6$ ✓
D. $V_3 + V_2 = V_1$ ✓
E. $V_3 + V_5 = V_6$

A. $-V_1 + V_2 + V_3 = 0 \quad / \times -1$

$\rightarrow V_1 - V_2 - V_3 = 0$

$\boxed{V_1 = V_2 + V_3}$

$-V_1 + V_2 + V_5 + V_6 = 0$

$V_1 = V_2 + V_5 + V_6$

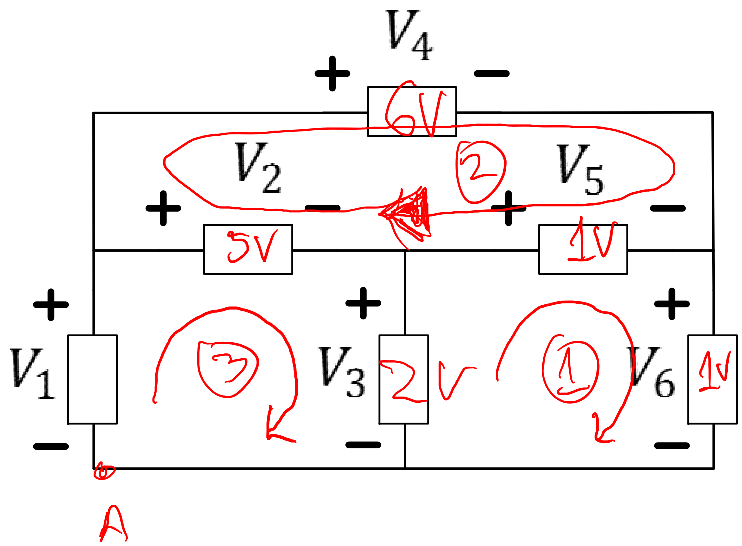
$-V_1 + V_4 + V_6 = 0$

$V_6 = V_1 - V_4$

$-V_3 + V_5 + V_6 = 0$

$\boxed{V_6 = V_3 - V_5}$

Missing voltages can be obtained using KVL.



In History…

The conceptual theories of electricity held by **Georg Ohm** were generalized in **Gustav Kirchhoff**'s laws (1845). Later, **James Clerk Maxwell**'s equations (1861) generalized the work done by Kirchhoff, Ampere, Faraday, and others.

ECE 329 Fields and Waves I

Explore More!

$$\oint\!\!\!\oint_{\partial\Omega} \mathbf{E}\cdot d\mathbf{S} = \frac{1}{\varepsilon_0}\iiint_{\Omega} \rho\, dV$$

$$\oint\!\!\!\oint_{\partial\Omega} \mathbf{B}\cdot d\mathbf{S} = 0$$

$$\oint_{\partial\Sigma} \mathbf{E}\cdot d\boldsymbol{\ell} = -\frac{d}{dt}\iint_{\Sigma} \mathbf{B}\cdot d\mathbf{S}$$

$$\oint_{\partial\Sigma} \mathbf{B}\cdot d\boldsymbol{\ell} = \mu_0\iint_{\Sigma} \mathbf{J}\cdot d\mathbf{S} + \mu_0\varepsilon_0\frac{d}{dt}\iint_{\Sigma} \mathbf{E}\cdot d\mathbf{S}$$

Maxwell's equations in Integral Form
Image Credit: Wikipedia.org

L5Q3: What are the values of the voltages V_1, V_2 and V_6 if $V_3 = 2\,V, V_4 = 6\,V, V_5 = 1\,V$?

1 $-V_3 + V_5 + V_6 = 0$

$V_6 = V_3 - V_5 = 2V - 1V = 1V$

2 $V_4 - V_5 - V_2 = 0$

$V_4 - V_5 = V_2 = 6V - 1V = 5V$

3 $-V_1 + V_2 + V_3 = 0$

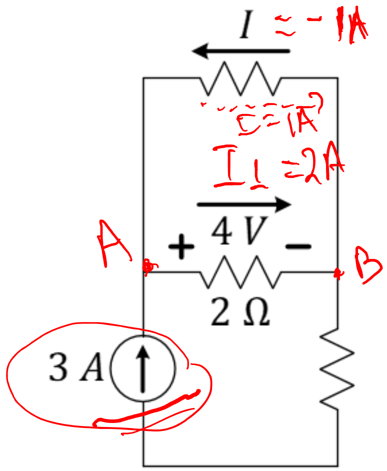
$V_1 = V_2 + V_3$

$V_1 = 7V$

Examples

KVL: $V + V_1 + V_2 = 0$

L5Q4: Find the value of I.



A. $-3\ A$
B. $-2\ A$
C. $-1\ A$
D. $1\ A$
E. $2\ A$

$$I_1 = \frac{\Delta V}{R} = \frac{4V}{2\Omega} = 2A$$

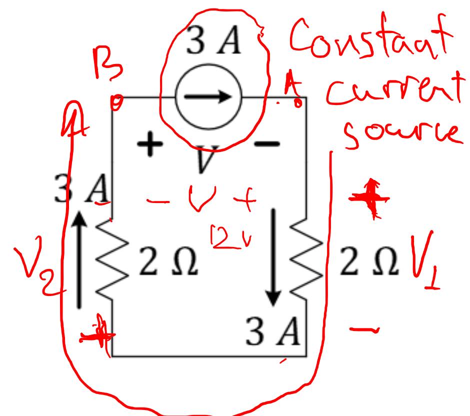
$$V_{AB} = 4V$$

at node A KCL: $3A + I = 2A$

$$I = 2A - 3A = -1A$$

$$\boxed{I = -1A}$$

L5Q5: Find the value of V.



$I = 3A$

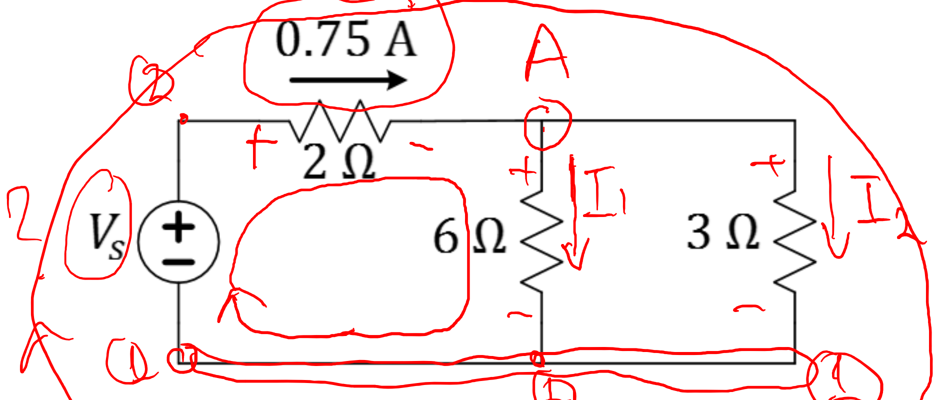
A. $-12\ V$
B. $-6\ V$
C. $-3\ V$
D. $6\ V$
E. $12\ V$

$$V_1 + V_2 + V = 0$$

$$(3A \cdot 2\Omega) + (3A \cdot 2\Omega) + V = 0$$

$$\boxed{V = -12V}$$

Circuits solved with Ohm's + KCL + KVL



Node A KCL

① $0.75A = I_1 + I_2$

② $-V_s + (2\Omega \cdot 0.75A) + (6\Omega \cdot I_1) = 0$

③ $-V_s + (2\Omega \cdot 0.75A) + (3\Omega \cdot I_2) = 0$

② − ③: $6\Omega \cdot I_1 - 3\Omega \cdot I_2 = 0$

L5Q6: What is the value of the source voltage?

L5Q7: How much power is the source supplying?

$I_1 = 0.25A \quad I_2 = 0.5A$

L5Q8: How much power is each resistance consuming?

$\boxed{V_s = 3V}$

$P_s = V_s \cdot I$

Q7: $P_s = 3V \cdot (0.75A) = \boxed{\frac{9}{4} W}$

Q8: $P_{6\Omega} = I_1^2 (6\Omega) = \boxed{\frac{3}{8} W}$ $\quad P_{3\Omega} = I_2^2 \cdot (3\Omega) = \boxed{\frac{9}{8} W}$

L5 Learning Objectives

a. Identify and label circuit nodes; identify circuit loops
b. Write node equation for currents based on KCL
c. Write loop equations for voltages based on KVL
d. Solve simple circuits with KCL, KVL, and Ohm's Law
e. Calculate power in circuit elements, verify conservation

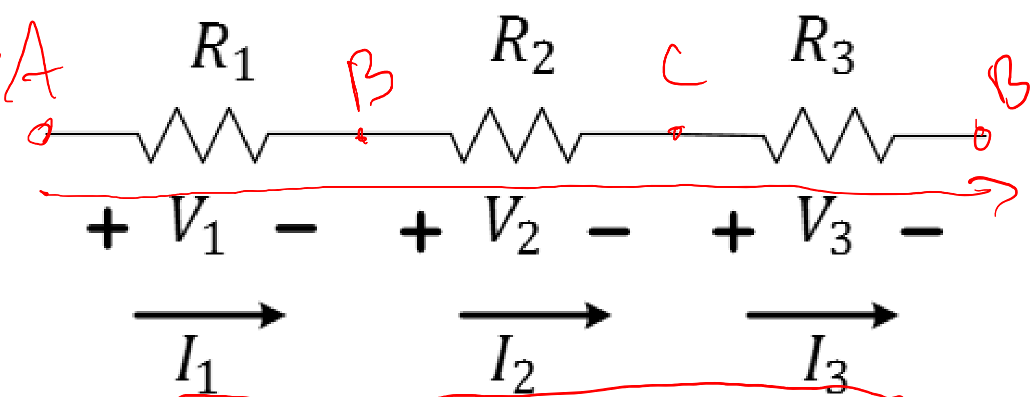
Lecture 6: Current and Voltage Dividers

- Series Connections, Equivalent Resistance, Voltage Divider
- Parallel Connections, Equivalent Resistance, Current Divider
- Power Dissipation in Series and Parallel Resistive Loads
- Example Problems and Practice

Series Connection

Series connections share the same current

Jel/jel

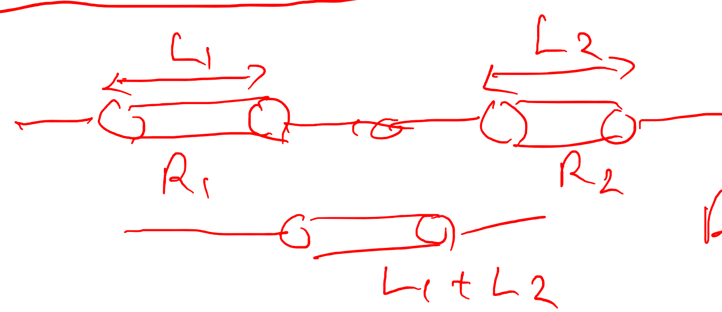


$= \text{Sel/jel}$

I

$$\boxed{I_1 = I_2 = I_3 \text{ because of KCL}}$$

$$R = \rho \frac{L}{A}$$

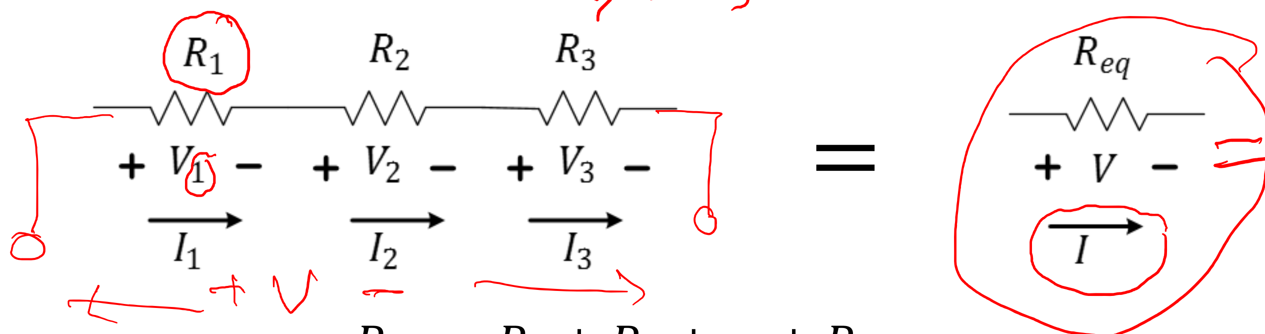


$R_{eq} = R_1 + R_2$

Equivalent Resistance of Series Resistors

Resistances in series add up

$I = I_1 + I_2 + I_3$



$= V_1 + V_2 + V_3$

$$R_{eq} = R_1 + R_2 + \cdots + R_N$$

$R = \rho \frac{L}{A}$

This can be intuitive: think of telegraphy wires in series.

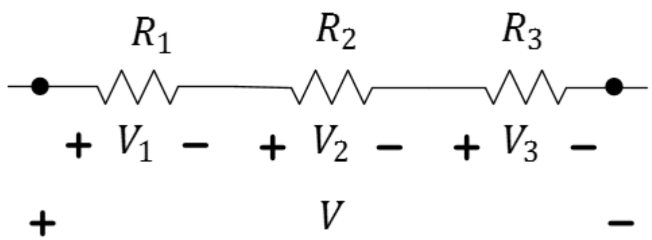
$$\boxed{R_{eq} = \sum_{i=1}^{N} R_i}$$

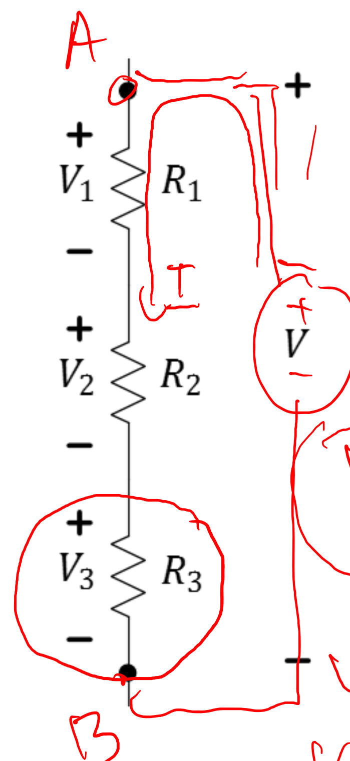
Voltage Divider Rule (VDR)

$R_{eq} = R_1 + R_2 + R_3$

When a voltage divides across resistors in series, more voltage drop appears across the largest resistor.

$$\boxed{V_k = \frac{R_k}{R_{eq}} \cdot V}$$





KVL

$V = IR_1 + IR_2 + IR_3$

$V = I(R_1 + R_2 + R_3)$

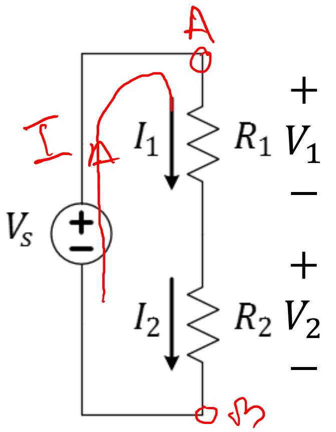
$V_3 = I \cdot R_3$

$$\boxed{V_3 = \cancel{V} \frac{R_3}{R_1 + R_2 + R_3}}$$

L6Q1: Can a voltage across one of the resistors be higher than the total V?

NO

L6Q2: If $R_1 < R_2$, which of the following is true?



$I = I_1 = I_2$

A. $V_1 < V_2$ and $I_1 < I_2$

70% → B. $V_1 < V_2$ and $I_1 = I_2$

C. $V_1 = V_2$ and $I_1 = I_2$

20% → D. $V_1 > V_2$ and $I_1 = I_2$

E. $V_1 > V_2$ and $I_1 > I_2$

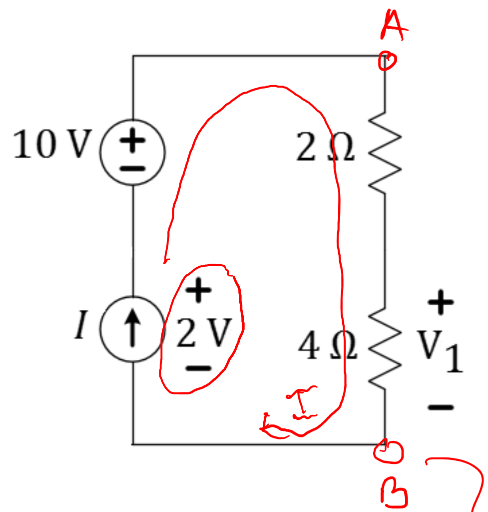
$\uparrow V_R = V \frac{R_x \uparrow}{R_{eq}}$

$R_{eq} = R_1 + R_2$

$R_1 < R_2$

$\boxed{V_1 < V_2}$

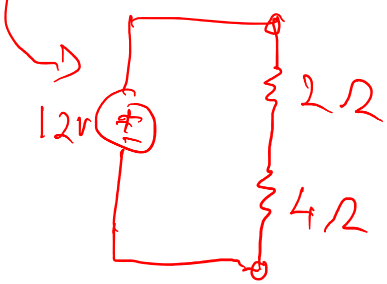
L6Q3: Use VDR to find V_1.



$V_1 = 12 \frac{4\Omega}{4\Omega + 2\Omega} = 8V$

$V_{AB} = 2V + 10V$

$V_{AB} = 12V$



A. $V_1 \leq -6\,V$

B. $-6 < V_1 \leq -2\,V$

C. $-2 < V_1 \leq 2\,V$

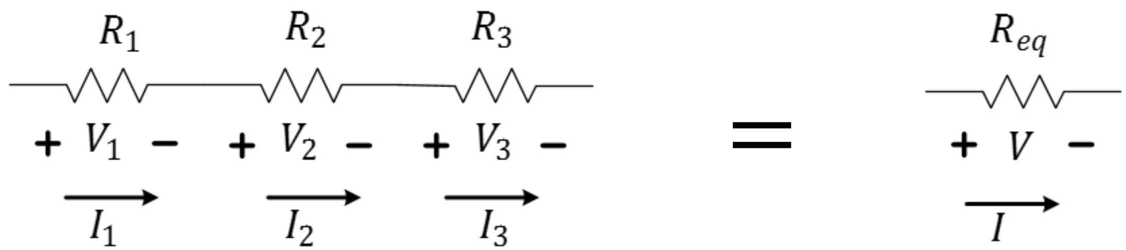
D. $2 < V_1 \leq 6\,V$

E. $6\,V < V_1$

KVL $(2\Omega \cdot I) + (4\Omega \cdot I) - 2V - 10V = 0$

$I = 2A \quad V_1 = 4\Omega \cdot 2A = 8V$

VDR Derivation

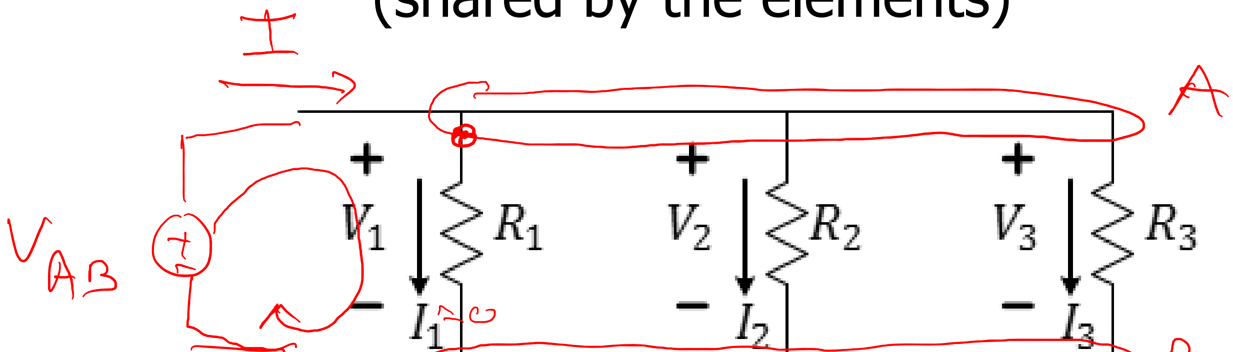


$I = I_1 = I_2 = I_3$

Since $I = I_k$, $\quad \frac{V}{R_{eq}} = \frac{V_k}{R_k}$ by Ohm's Law. So, $\boxed{V_k = \frac{R_k}{R_{eq}} \cdot V}$

Parallel Connection

Parallel connections share the same voltage potentials at two end nodes (shared by the elements)



$V_1 = V_2 = V_3$ because of KVL

$I_1 \neq I_2 \neq I_3$

KCL node A

$\boxed{I = I_1 + I_2 + I_3}$

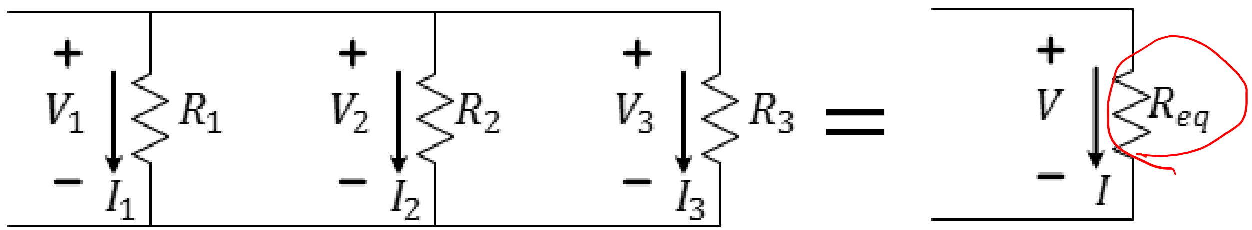
L6Q4: Are appliances in your house/apartment connected in series or in parallel?

A. B.

KVL $\boxed{V_{AB} = V_1 = V_2 = V_3}$

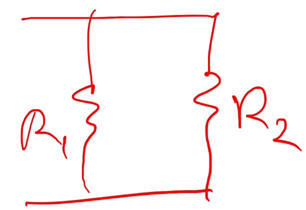
$V_{AB} - V_1 = 0 \Rightarrow V_{AB} = V_1$

Equivalent Resistance of Parallel Resistors



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

If $N = 2$, $\quad R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$



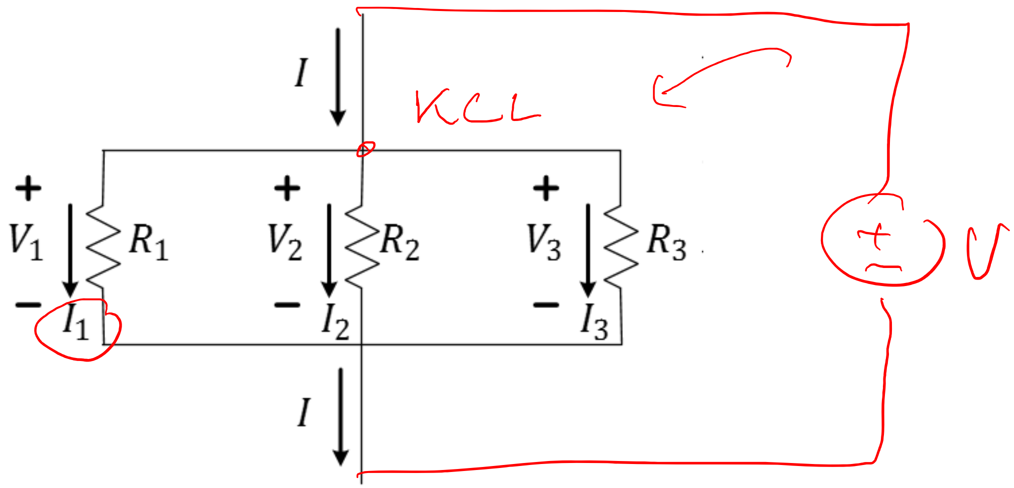
Adding resistance in parallel always brings resistance down!
This can be intuitive: think of combining wire strands to make a thicker wire.

$$\downarrow R = \rho \frac{L}{A \uparrow}$$

Current Divider Rule (CDR)

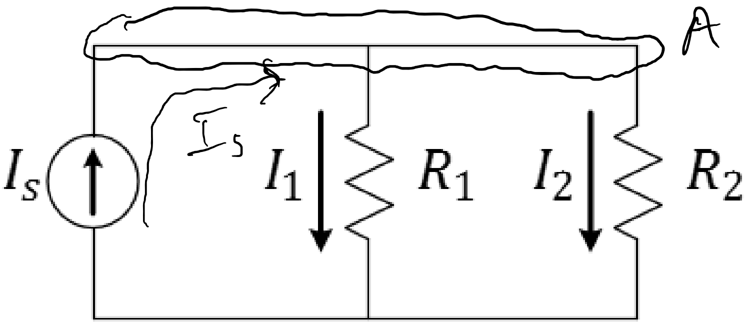
When a current divides into two or more paths, more current will go down the path of lowest resistance.

$$\boxed{I_k = \frac{R_{eq}}{R_k} \cdot I}$$



$I = I_1 + I_2 + I_3$

L6Q5: If $R_1 < R_2$, which of the following is true?



A. $I_1 < I_2 < I_s$
B. $I_1 < I_s < I_2$
C. $I_2 < I_1 < I_s$
D. $I_2 < I_s < I_1$
E. $I_s < I_2 < I_1$

L6Q6: In a parallel connection, does a smaller or larger resistor absorb more power?
A. smaller
B. larger

$$\boxed{I_k = I \frac{R_{eq}}{R_k}}$$

$I_s = I_1 + I_2$

node A KCL

$$\boxed{I_s = I_1 + I_2}$$

$R_1 < R_2$

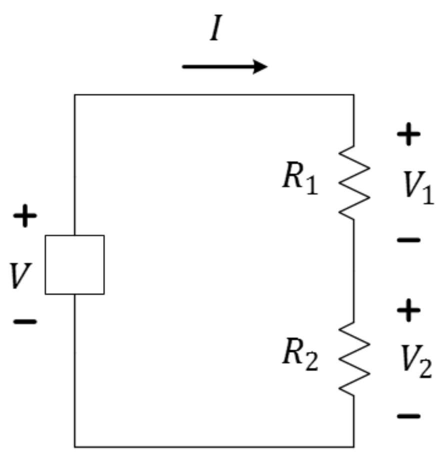
$I_1 > I_2$

$R_1 < R_2$

$I_1 > I_2$

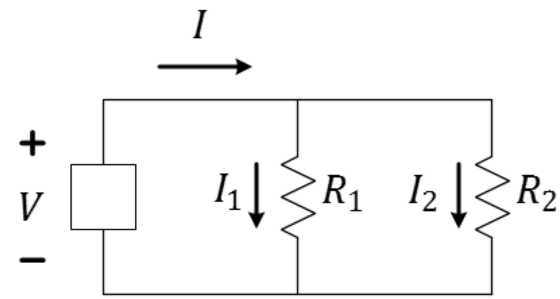
$$\boxed{I_s > I_1 > I_2}$$

VDR and CDR for Two Resistances



$$\boxed{V_1 = \frac{R_1}{R_1 + R_2} V}$$

$$V_2 = \frac{R_2}{R_1 + R_2} V$$



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

$$\boxed{I_1 = \frac{R_2}{R_1 + R_2} I} \qquad I_2 = \frac{R_1}{R_1 + R_2} I$$

$$I_1 = I \frac{R_{eq}}{R_1}$$

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

Bad Idea: try to memorize these formulae.
Good Idea: try to note trends and understand concepts !

Example, if $R_1 = 1\ \Omega$ and $R_2 = 2\Omega$, then $V_2 : V_1$ will be in a $2:1$ ratio for the series circuit.

Why?

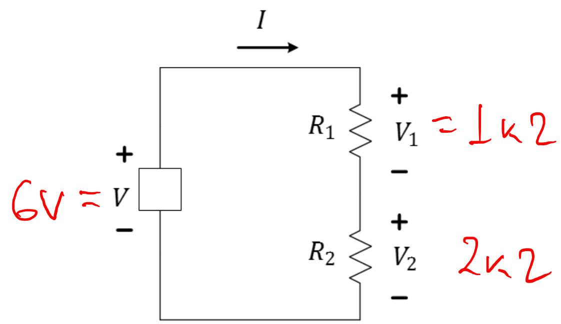
If $R_1 = 1\ \Omega$ and $R_2 = 2\Omega$, then $I_2 : I_1$ will be in a $1:2$ ratio for the series circuit.

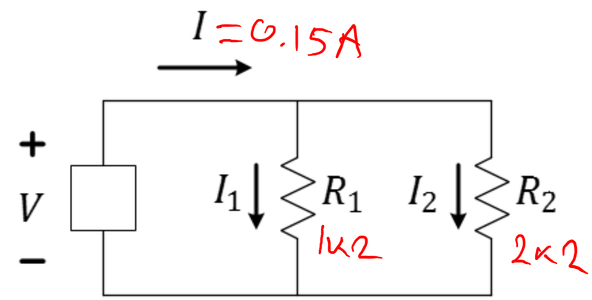
$$\boxed{R_{eq} = \frac{R_1 R_2}{R_1 + R_2}}$$

$$I_2 = I \frac{R_{eq}}{R_2}$$

$$I_1 = I \frac{R_1 R_2}{R_1 + R_1} \cdot \frac{1}{R_1}$$

VDR and CDR for Two Resistances





L6Q7: If 6V falls across a series combination of 1kΩ and 2kΩ, what is V across 2kΩ?

$V_2 = ?$

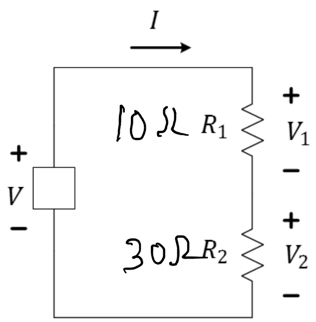
L6Q8: If 0.15A flows through a parallel combo of 1kΩ and 2kΩ, what is I through 2kΩ?

$I_2 = ?$

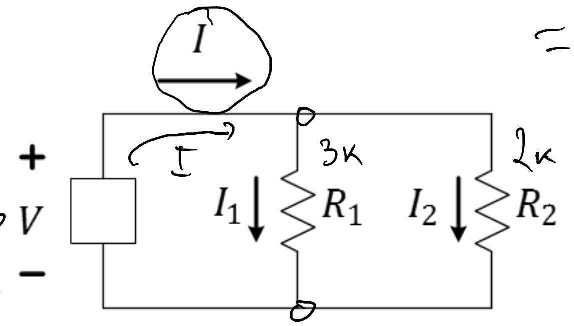
$$V_{2k} = V \frac{R_2}{R_1 + R_2} = 6V \frac{2k\Omega}{1k\Omega + 2k\Omega} = \underline{\underline{4V}}$$

$$I_{2k} = I \frac{R_1}{R_1 + R_2} = (0.15A) \cdot \frac{1k}{1k + 2k} = \underline{\underline{0.05A}}$$

VDR and CDR for Two Resistances



$P=300\,mW$



$P_{R2}=I_2\cdot V=$

$=\frac{3}{5}IV=\frac{3}{5}\,300\,mW$

$\boxed{=180\,mW}$

$P_{R1}=I_1\cdot V=$

$=\frac{2}{5}I\cdot V=$

$=\frac{2}{5}\cdot 300\,mW=\boxed{120\,mW}$

L6Q9: If a source supplies 60W to a series combination of 10Ω and 30Ω, what is the power absorbed by the 10Ω resistor? What is absorbed by the 30Ω resistor?

$P=V\cdot I=300\,mW$

$I_1=I\frac{R_2}{R_1+R_2}=I\,\frac{2k}{5k}$ $\quad I_2=I\frac{R_1}{R_1+R_2}=I\,\frac{3k}{5k}$

L6Q10: If a source supplies 300mW to a parallel combination of 3kΩ and 2kΩ, what is the power absorbed by the 3kΩ resistor? What is absorbed by the 2kΩ resistor?

Q9

$P=V\cdot I=60\,W$

$P_{R1}+P_{R2}=60\,W$

$V_1=V\frac{R_1}{R_1+R_2}=V\,\frac{10}{40}$

$V_2=V\frac{R_2}{R_1+R_2}=V\,\frac{30}{40}$

$P=60\,w$

$P_{30}=V_2\cdot I=\frac{30}{40}\cdot V\cdot I=\frac{30}{40}\cdot 60\,W=45\,W$

$P_{10}=V_1\cdot I=\frac{10}{40}\cdot V\cdot I=\frac{1}{4}\,60\,W=15\,W$

battery → $\boxed{+60\,W}$

L6 Learning objectives

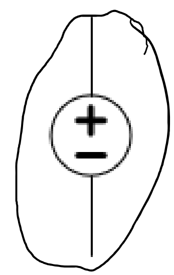
a. Identify series and parallel connections within a circuit network
b. Find equivalent resistance of circuit networks
c. Estimate resistance by considering the dominant elements
d. Apply rules for current and voltage division to these networks
e. Apply conservation of energy to components within a circuit network

Lecture 7: More on Sources and Power

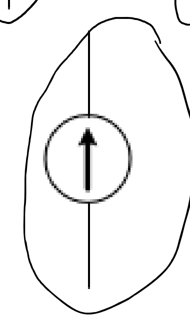
- The Meaning of Current and Voltage Sources
- Labeling of Current and Voltage and Sign of Power

Voltage and Current Sources Can Produce or Consume Power and Energy

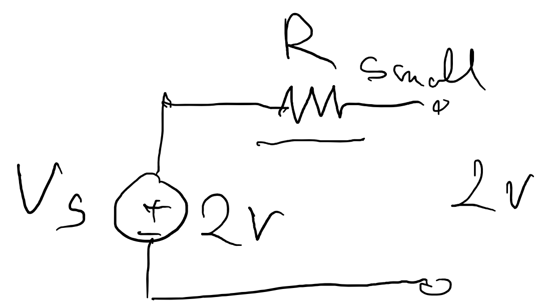
Voltage Source



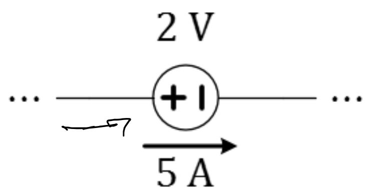
Current source



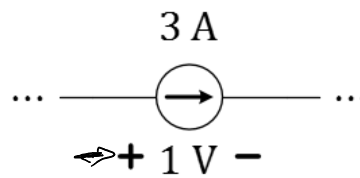
- [Ideal] sources in a circuit are mathematical models
- Can be used to model real devices (or parts of circuit)
- Voltage sources have (calculable) currents through them
- Current sources have (calculable) voltages across them
- Source elements can produce or consume energy



Which of the sources are delivering power?



$P > 0$ consuming



$P > 0$ consuming

A. The voltage source only
B. The current source only
C. Both
D. Neither
E. Not enough information to tell

delivering power

$5V = V$

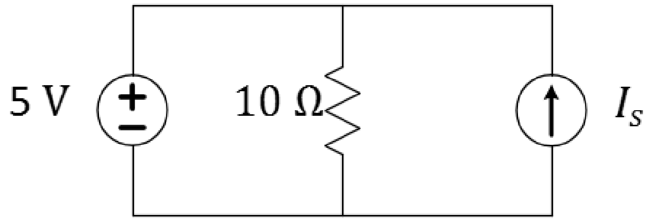
consumer

$P_S = V \cdot I$

$P_R = V \cdot I$

$P_S + P_R = 0$

Either or Both Sources Can Supply Power

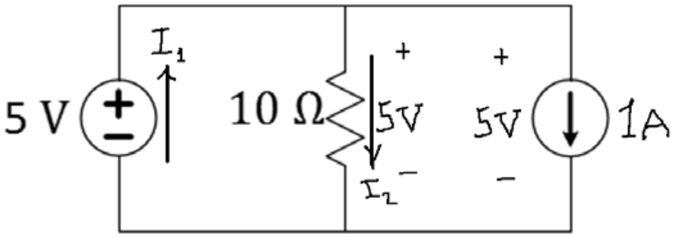


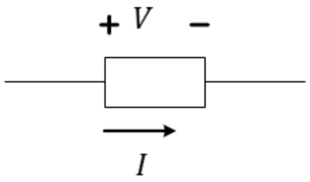
L7Q1: For what values of I_s do both sources supply power?

L7Q2: For what values of I_s does only the current source supply power?

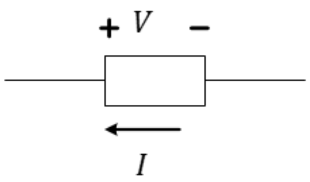
L7Q3: For what values of I_s does only the voltage source supply power?

Claim: Labeling Voltage and Current Polarity Is Arbitrary. When *does* it matter?





"Current downhill" is preferable for resistors



"Current uphill" can be convenient for sources.

If a resistor, then…

$$V = IR$$

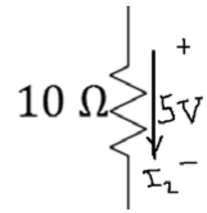
$$V = -IR$$

Answer #1: When applying Ohm's Law,
it is the "downhill current" that equals V over R: $I_{+\to-} = \frac{V}{R}$

Consideration of Polarity Assignments

L7Q4: In what direction does a positive current flow through a resistor?

A. “Downhill” of voltage
B. “Uphill” of voltage
C. Could be either A or B



L7Q5: In what direction does a positive current flow through a battery?

A. “Downhill” of voltage
B. “Uphill” of voltage
C. Could be either A or B

Continued: When *does* polarity assignment matter?

Answer #2: When the sign of power is important.

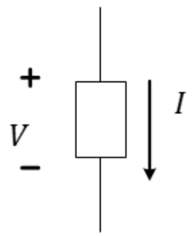
Recall: power (watts) is energy (joules) divided by time (sec), or volts times current

$$\boxed{P(t) = V(t)I(t)}$$

$$P = VI$$

if constant (aka. DC or Direct Current). Using the standard polarity labeling:

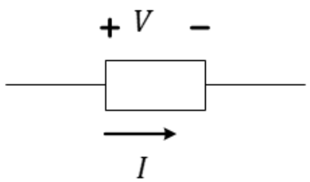
$P = \ V_{+\,-}\ \ I_{+\rightarrow -}$



$$\boxed{P < 0} \Rightarrow Element\ \boxed{delivers}\ power\ to\ the\ circuit$$

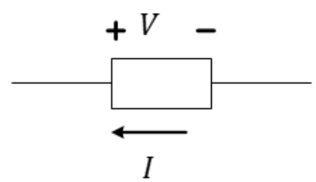
$$\boxed{P > 0} \Rightarrow Element\ \boxed{absorbs}\ power\ from\ the\ circuit$$

Recap of labeling implication



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

$$P = VI$$



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

$$P = -VI$$

This way, power is defined such that it is negative when it is supplied (sourced) and positive when it is absorbed (sinked).

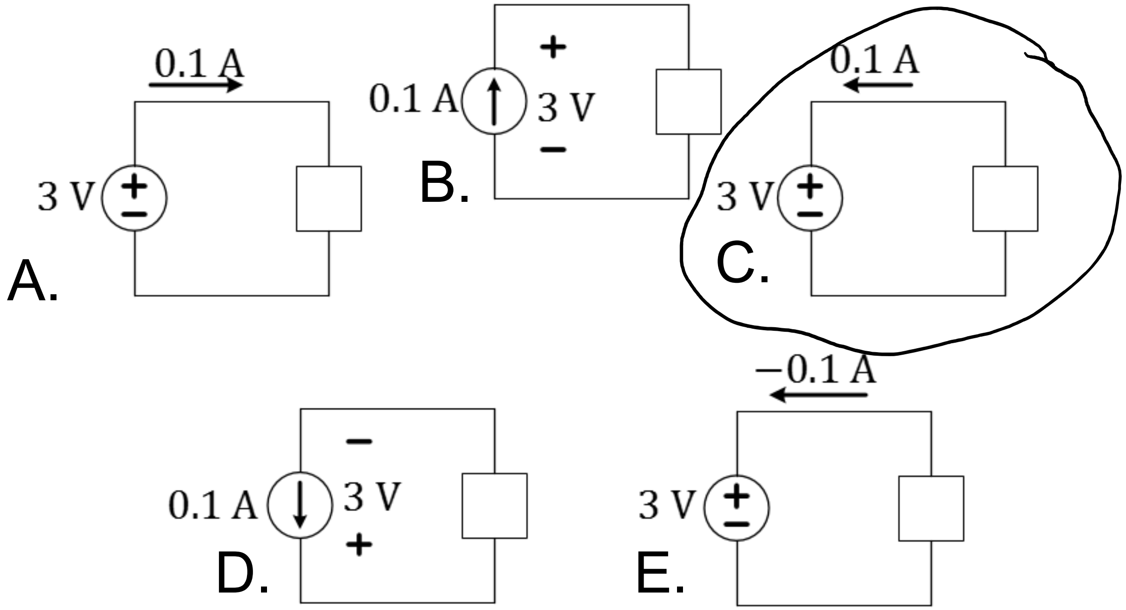
L7Q6: With power defined as above,
what is the sum of powers for all circuit elements?

Universal:

Ohm's Law: $I_{+\to-} = \frac{V}{R}$

Power Eqn: $P = VI_{+\to-}$

Which of the sources below absorbs power?



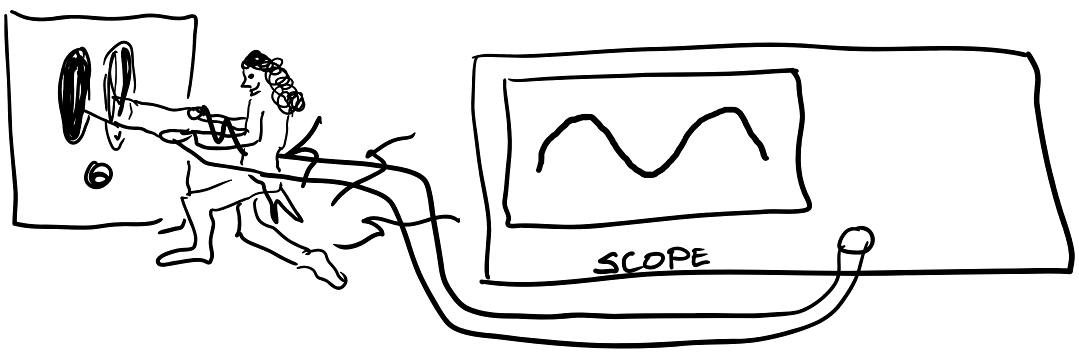
L7 Learning Objectives

a. Use “downhill current” to correctly apply Ohm’s law in a resistor (depending on labeling)
b. Use “downhill current” to determine whether power is absorbed or supplied by an element

Lecture 8: RMS and Power

- Time Varying Voltage Source – Sinusoidal, Square, Etc.
- Root-Means-Square Voltage (RMS) of a Waveform

Voltage from the wall plug is *sinusoidal*



In History…

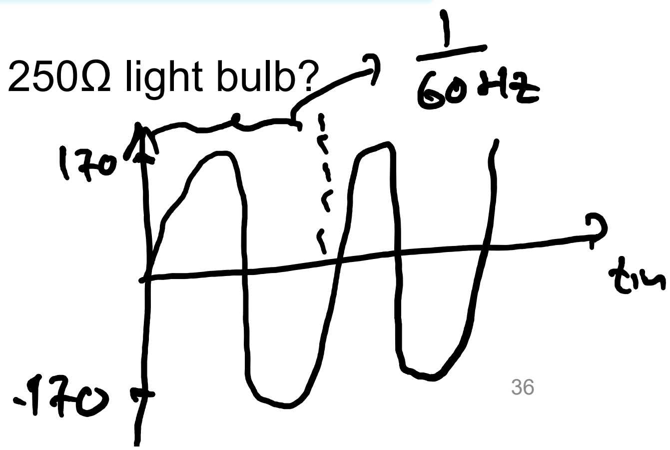
In the 1880's and 1890's, **Nikola Tesla** played a large role in improving DC motors, developing AC motors and generators, and developing many high-frequency/high-voltage experiments including many in the area of remote control and wireless telephony. **Marconi**'s 1901 cross-Atlantic wireless transmission likely infringed upon a few of Tesla's nearly 300 patents.

L8Q1: What is the peak instantaneous power absorbed by a 250Ω light bulb?

$V_{rms} = 110V$

$V_{max} = (110V) \cdot \sqrt{2} = 170V$

$P = V_{max}^2 / R = 170V^2 / 250\Omega = 115.6W$



Time Average Power

(similar equation for any time-average)

$$P_{avg} = \frac{AREA_{in\,T}}{T},$$
$$T = period$$

For non-periodic signals (e.g. constant white noise) use

$$T = sufficient\ length\ observation\ interval$$

Root-Mean-Square averages

RMS is meaningful when interested in power production/dissipation in AC.

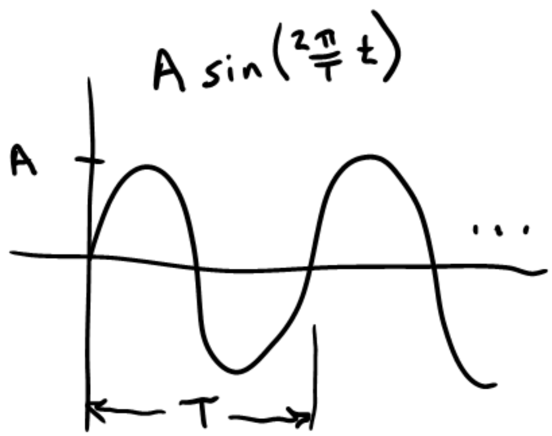
$$V_{RMS} = \sqrt{Average[v^2(t)]}$$

1. Sketch $v^2(t)$
2. Compute $Average[v^2(t)]$
3. Take $\sqrt{}$ of the value found in part 2.

Calculating P_{avg} and V_{rms}

$$\sin^2\theta = \frac{1}{2}(1-\cos 2\theta)$$

$$Trig\ identity: \cos(A)\cos(B) = \frac{1}{2}[\cos(A-B)+\cos(A+B)]$$



$$V_{avg} = \frac{1}{T}\int_0^T v(t)\,dt \qquad V_{rms} = \sqrt{\frac{1}{T}\int_0^T v^2(t)\,dt}$$

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T A^2 \sin^2\left(\frac{2\pi}{T}t\right)dt}$$

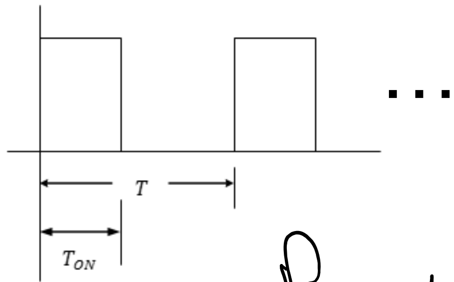
$$= \sqrt{\frac{1}{T}\int_0^T A^2 \frac{1}{2}\left[1-\cos\frac{4\pi t}{T}\right)dt} =$$

$$= \frac{A}{\sqrt{2}}\sqrt{\frac{1}{T}\left[t - \frac{T}{4\pi}\sin\left(\frac{4\pi t}{T}\right)\right]_0^T} = \frac{A}{\sqrt{2}}\sqrt{\frac{1}{T}\left(T - \frac{T}{4\pi}(\sin 4\pi - 0\right)} = \frac{A}{\sqrt{2}}$$

L8Q2: What is the average power absorbed by a 250Ω light bulb if A = 170V?

$$P_{Avg} = \frac{V_{rms}^2}{R} = \frac{\left(\frac{170}{\sqrt{2}}\right)^2}{250} = 57.8 \text{ W}$$

Calculating P_{avg} and V_{rms}



$Duty\ Cycle\ Definition: \frac{T_{ON}}{T}$

$$P_{Avg} = V_{rms}^2 / R = \left(A\sqrt{\frac{T_{on}}{T}}\right)^2 \frac{1}{R} = \frac{A^2}{R} \frac{T_{on}}{T}$$

$$P_{Avg,half} = \frac{A^2}{R} \frac{T_{on}/2}{T} = \frac{1}{2} \frac{A^2 T_{on}}{R\,T} = \frac{P_{Avg}}{2}$$

L8Q3: What happens to power and V_{rms} when T_{ON} is halved while T is unchanged?

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T v^2(t)\,dt} = \sqrt{\frac{1}{T}\int_0^{T_{on}} A^2\,dt} = \sqrt{\frac{1}{T} A^2 t\Big|_0^{T_{on}}} = A\sqrt{\frac{T_{on}}{T}}$$

$$V_{rms,half} = A\sqrt{\frac{T_{on}/2}{T}} = \frac{1}{\sqrt{2}} A\sqrt{\frac{T_{on}}{T}} = \frac{V_{rms}}{\sqrt{2}}$$

Always remember the fundamental definition of rms

i>clicker: Which equation provides the rms voltage of a PWM signal with a peak voltage of A volts?

A. A

B. $\frac{A}{2}$

C. $\frac{A}{\sqrt{2}}$

D. $\sqrt{Avg\{v^2(t)\}}$ where $v(t)$ is the waveform of the PWM signal.

E. None of these.

Remember, you want to learn concepts and not attempt to memorize formulae.

L8 Learning Objectives

a. Compute the time-average power from I(t), V(t) curves
b. Explain the meaning of V_{rms} and relationship to P_{avg}

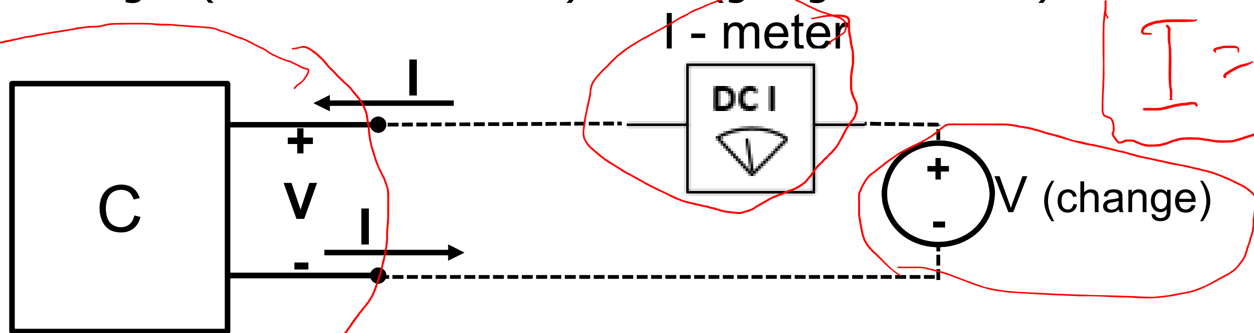
Lecture 9: IV Characteristics

- Measuring I-V Characteristics of Circuits
- Calculating I-V Characteristics of Linear Circuits
- Operating (I,V) point when Sub-circuits are Connected
- Power and the I-V Characteristics

Consider any circuit with two leads

It's DC (not changing in time) behavior can be described by relating V (between terminals) and I (going in and out).

$\boxed{I = f(V)}$

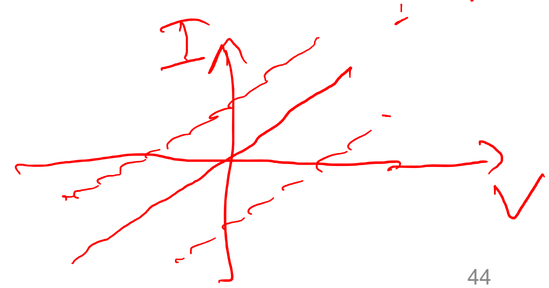


V	I
0	0
1	2
2	4
⋮	6

If the circuit is not too close to an ideal voltage source, the IV relationship can be measured like shown above.

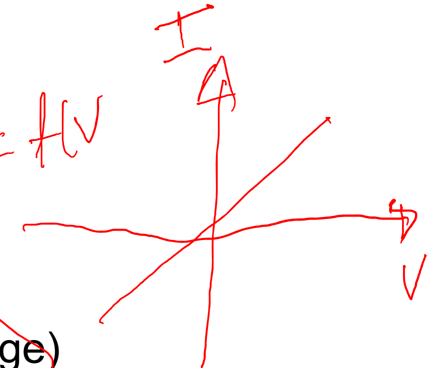
L9Q1: What is the voltage drop across an ideal current-meter (ammeter)?

$\Delta V = 0$

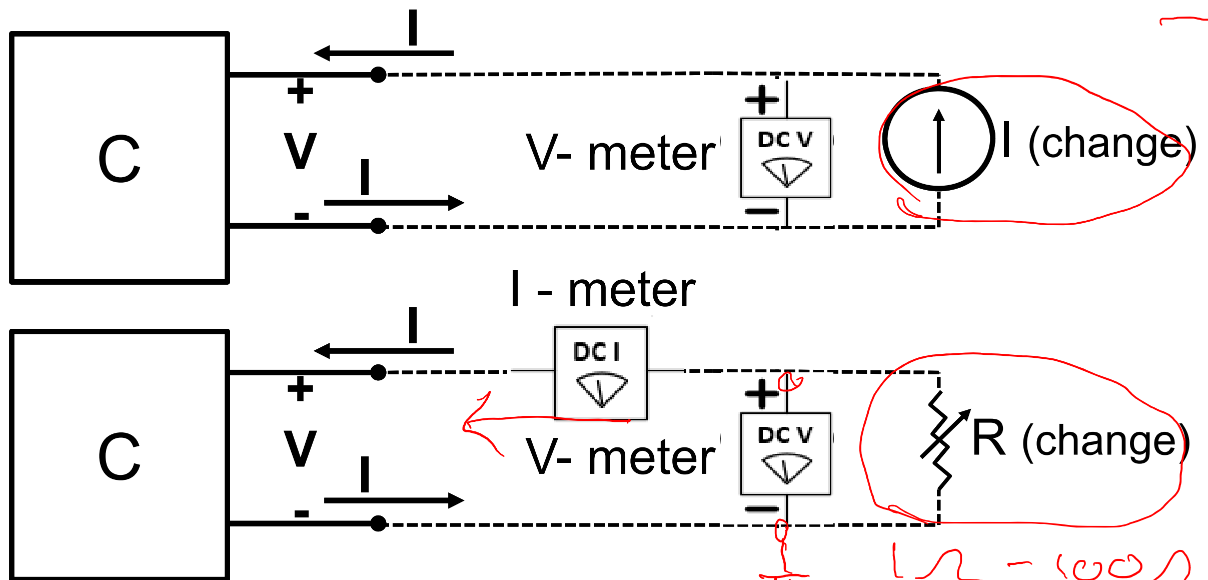


Alternative IV measurements

$I = f(V)$



I (mA)	V (measured)
0	
1	
2	



A variable resistor load is very practical when the circuit C provides power.

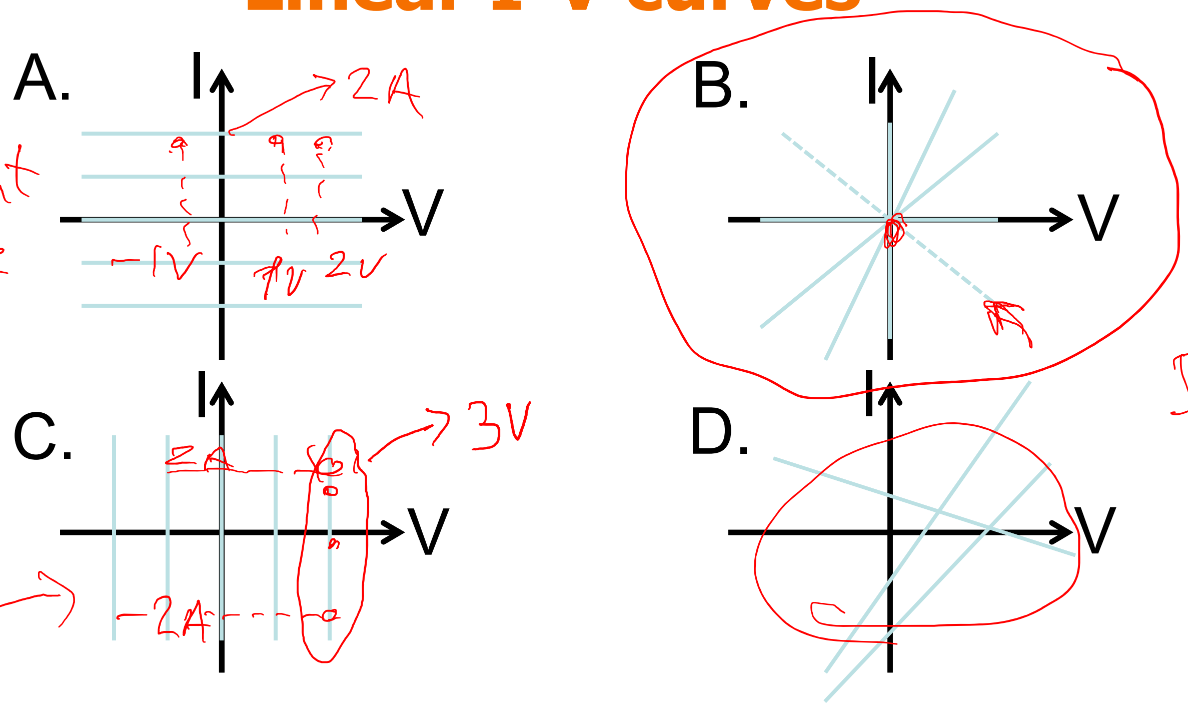
L9Q2: What is the current through an ideal voltage-meter (voltmeter)?

$V = IR$ $\qquad \boxed{I = 0}$ $\qquad R = \infty$

$I = \frac{V}{R} \Rightarrow R = \infty$

Linear I-V curves

Current Source



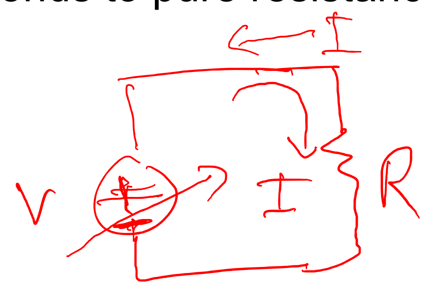
Voltage Source

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

L9Q3: Which set of graphs corresponds to pure resistances?

$V = I \cdot R$

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

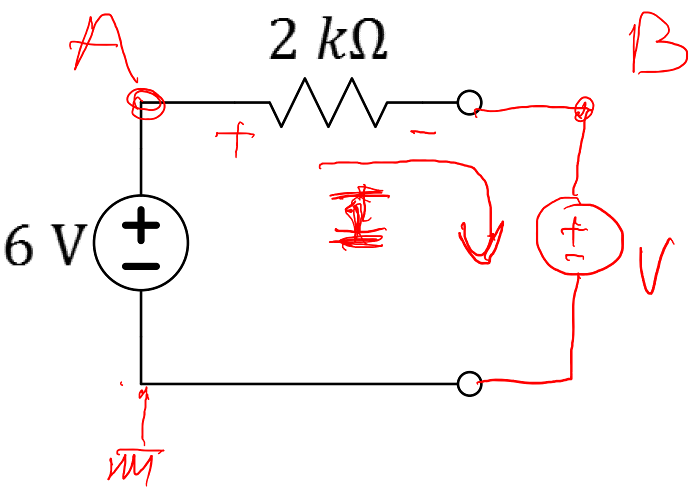


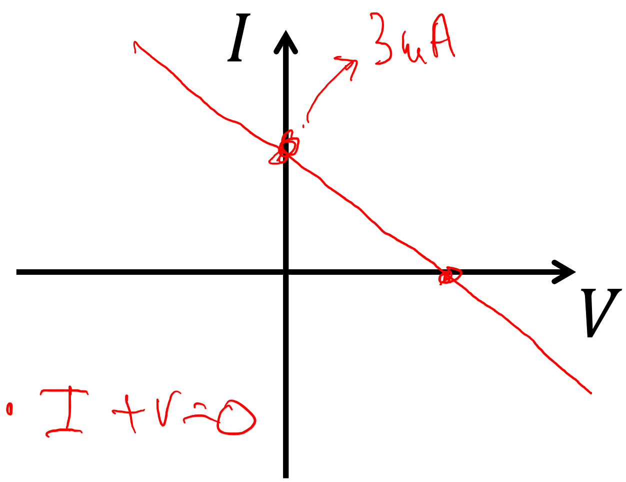
$V = 0$

$I = 0$

Simple Series Circuit

Show that the circuit has a linear IV characteristic.





$$-6 + 2k\Omega \cdot I + V = 0$$

$$2k\Omega \cdot I = 6 - V$$

L9Q4: What are the IV characteristics of the circuit above? Include the graph.

$V_A = 6V$

$V_B = V$

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

$\boxed{I = \frac{6-V}{R}}$

$\boxed{I = \frac{6-V}{2k}}$

$\rightarrow V = 0 \quad I = \frac{6}{2} = 3mA$

$\rightarrow I = 0 \quad V = 6V$

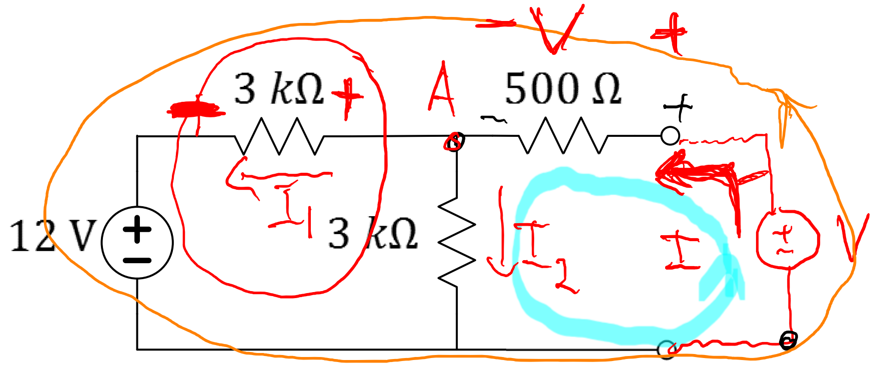
$0 = 3 - \frac{1}{2}V \quad V = 6V$

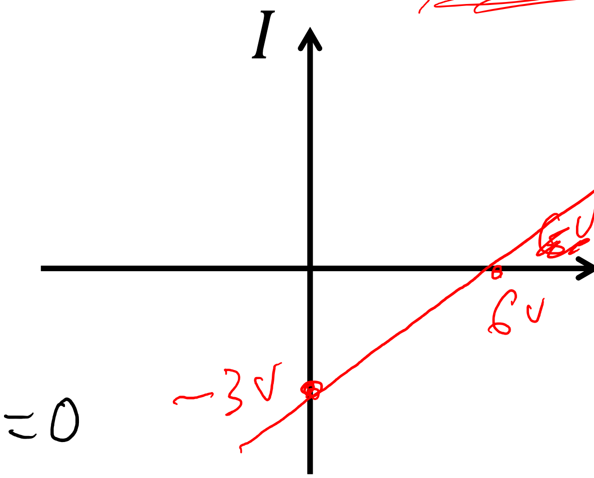
Embedded Voltage Source

Show that this circuit also has a linear IV characteristic.

$I = f(V)$

$V = IR$





KCL ①: $\cancel{I_1 + I = I_2}$ $\quad I_1 + I_2 = I$

KVL ②: $-V + 500 \cdot I + 3k\Omega \cdot I_2 = 0$

KVL ③: $-V + 500 \cdot I + 3k\Omega \cdot I_1 + 12 = 0$

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

$IR = -V$

$-V - IR = 0$

KVL: $-V + IR = 0$

$V = IR$

L9Q5: What are the IV characteristics of the circuit above? Include the graph.

$$\boxed{I = -3 + \frac{1}{2} V}$$

$V = 0 \quad I = -3$

$I = 0 \quad 0 = -3 + \frac{1}{2} V$

$V = 6V$

Why we care

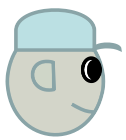
- Allows easy calculation of I and V when two sub-circuits are connected together
- Allows creating a simpler model of a given sub-circuit
- Helps understand nonlinear devices

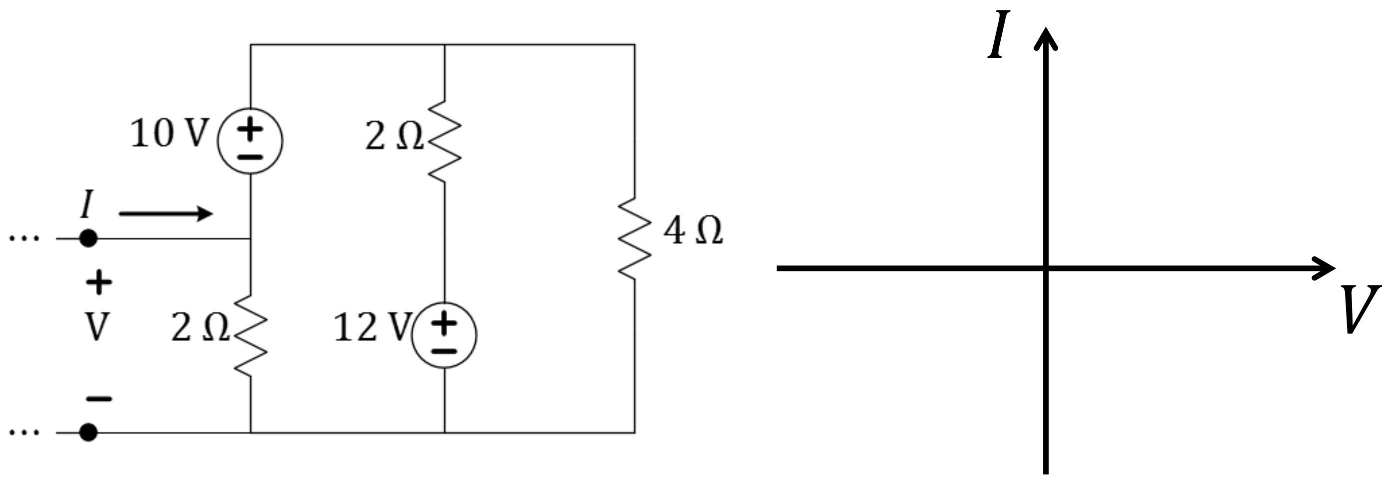
How to find IV lines

- Use ***circuit analysis*** for *variable* V
- Find two points (usually ***open*** and ***short***)
- Use R_{eff} and either ***open*** or ***short*** (Wednesday)

Linear I-Vs of source-resistor circuits

Any combination of current or voltage sources with resistor networks has a linear I-V (between any two nodes).

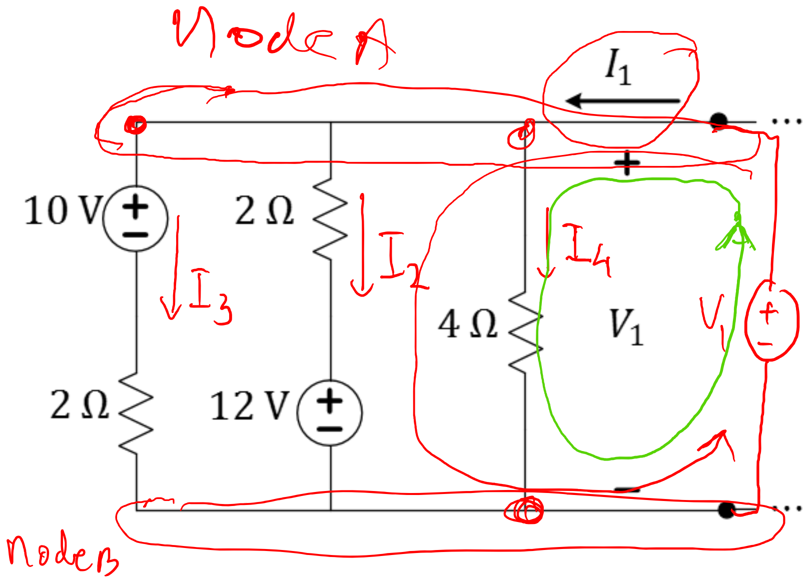


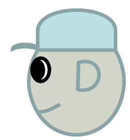


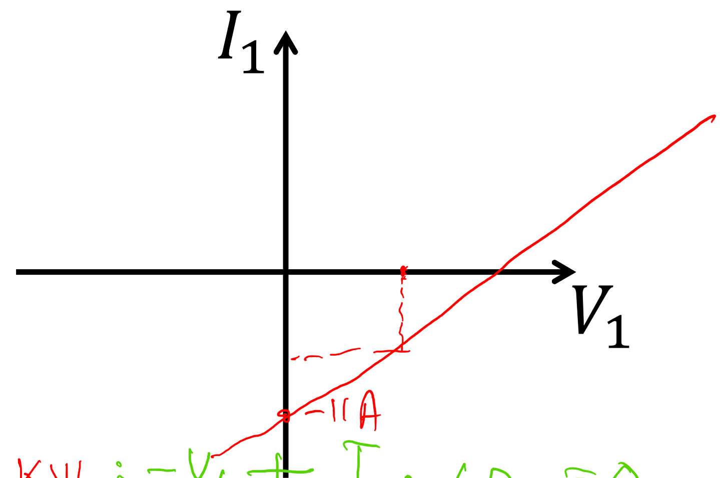
L9Q6: What are the current values I assumes when V is 0V, 2V, 4V?

I-V line for different nodes

$I_1 = f(V_1)$







KVL: $-V_1 + I_4 \cdot 4\Omega = 0$

KCL nodeA : ① $I_1 = I_2 + I_3 + I_4$

② $\boxed{I_4 = \frac{V_1}{4\Omega}}$

L9Q7: What are the current values taken by I_1 when V_1 is 0V, 2V, 4V?

$V_1 = 0 \quad I_1 = -11A$

$V_1 = 2V \quad I_1 = -8.5A$

③ $-V_1 + 2I_2 + 12 = 0$

④ $-V_1 + 10V + 2I_3 = 0$

$I_1 = \frac{5}{4} V_1 - 11$

Connecting two sub-circuits

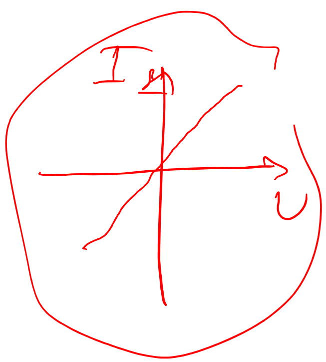
$-6V + (2k \cdot I) + V = 0$

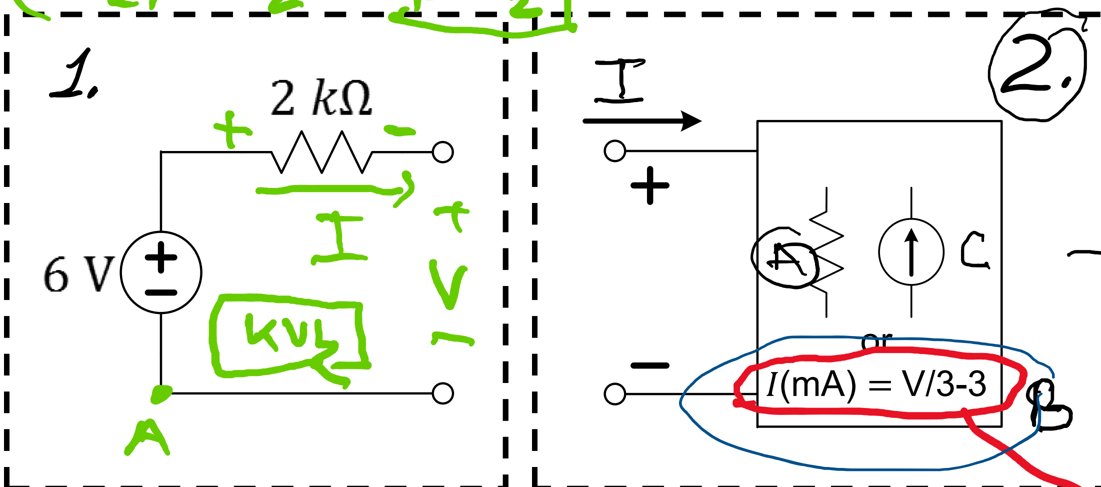
① $I = (6V/2) - V/2 = \boxed{3 - \frac{V}{2}}$

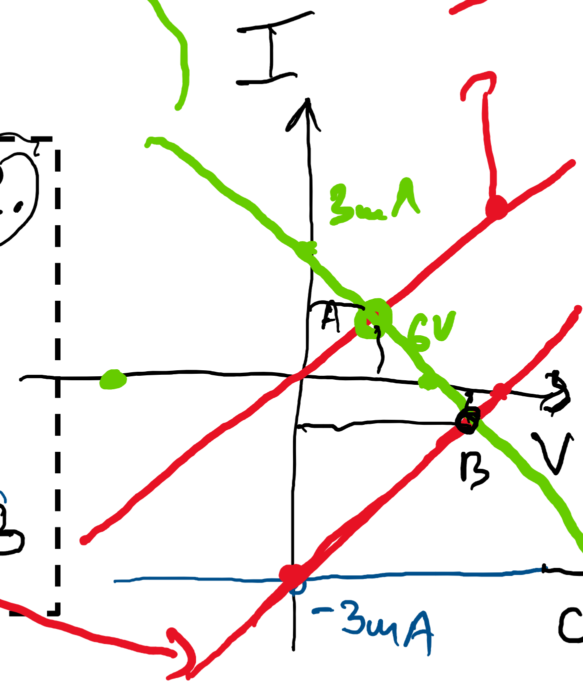
$I = 0 \quad V = +6V$

$V = 0 \quad I = 3$

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





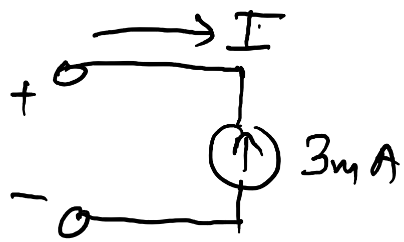


L9Q8: What are the IV characteristics of a 3 mA current source?
L9Q9: What are the IV characteristics of a 3 kΩ resistor?

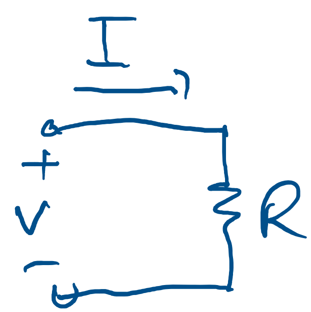
② $\boxed{I = \frac{V}{3} - 3}$

$V = 0 \quad I = -3$

$I = 0 \quad V = 9$



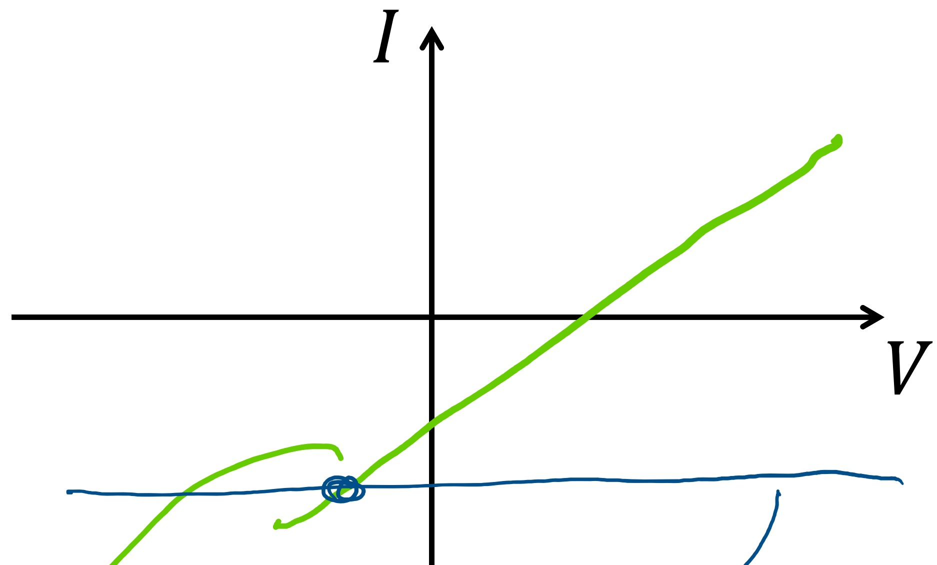
② $I = -3mA$



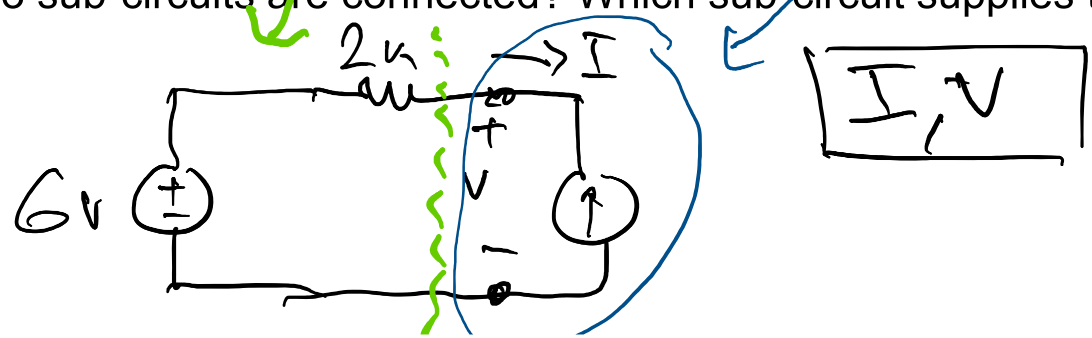
$V = IR$

② $I = \frac{V}{R}$

Connecting two sub-circuits (cont'd)



L9Q10: Considering the three choices for circuit #2, what is the operating point when the two sub-circuits are connected? Which sub-circuit supplies the power?



L9 Learning Objectives

a. Given one of the three sub-circuit descriptions (IV equation, IV line, diagram), find the other two

   Note that more than one circuit diagram fits an IV description

b. Quickly identify the IV representations of voltage and current sources, resistors, and combinations

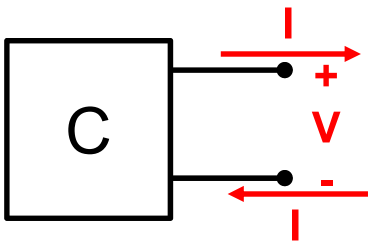
c. Find (V,I) operating points of connected sub-circuits

d. Calculate power flow between connected sub-circuits

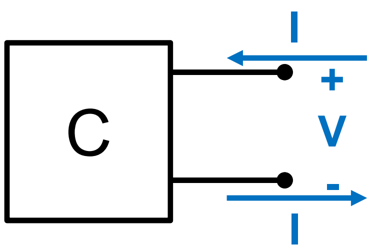
Lecture 10: Thevenin and Norton Equivalents

- Review of I-V Linear Equation
- Thevenin and Norton Equivalent Circuits
- Thevenin-Norton Transformation in Circuits
- Calculating R_{eff} by Removing Sources
- Problem Strategy and Practice

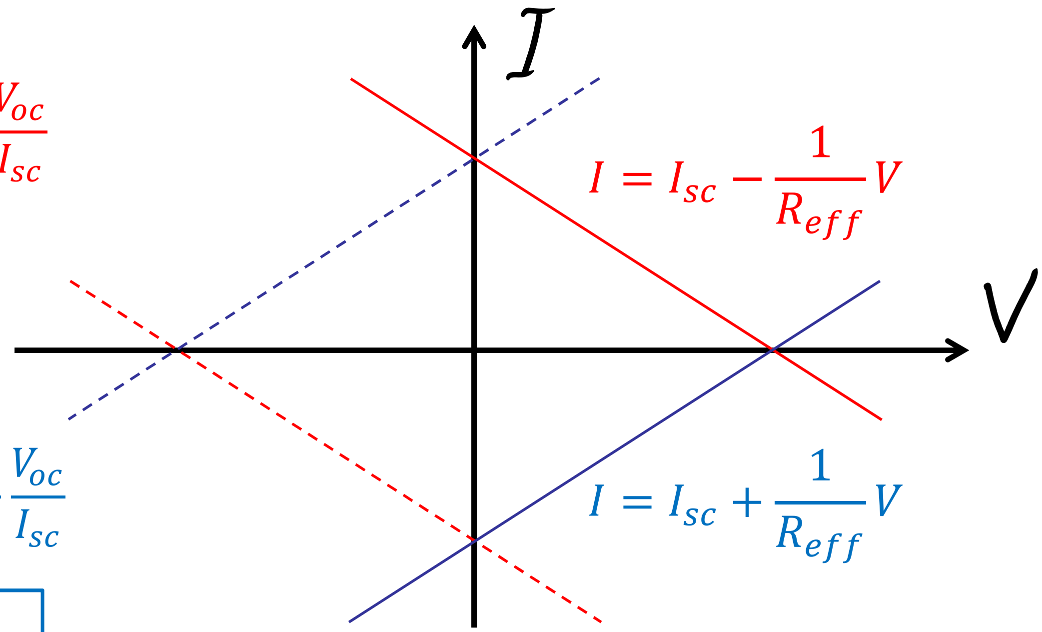
Relating I-V Line to Equation



$R_{eff} = \frac{V_{oc}}{I_{sc}}$



$R_{eff} = -\frac{V_{oc}}{I_{sc}}$



Universal: $I = I_{sc} - \frac{I_{sc}}{V_{oc}} V$

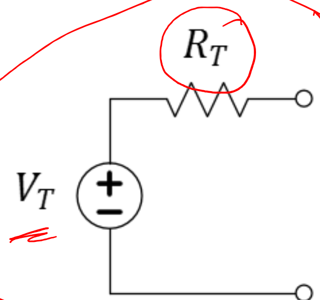
Thevenin and Norton Equivalents

$\boxed{R_{eff} = ? \quad V_{oc} = ? \quad I_{sc} = ?}$

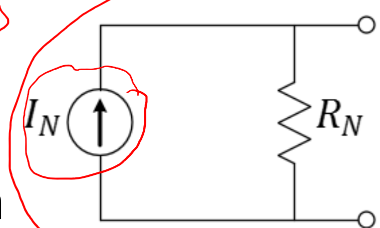
$V_T = V_{oc}$

$R_N = R_T = \frac{I_{sc}}{V_{oc}}$

$I_N = I_{sc}$



The circuit on the left and the circuit on the right can be made to behave identically by the choice of values as seen through the terminals.

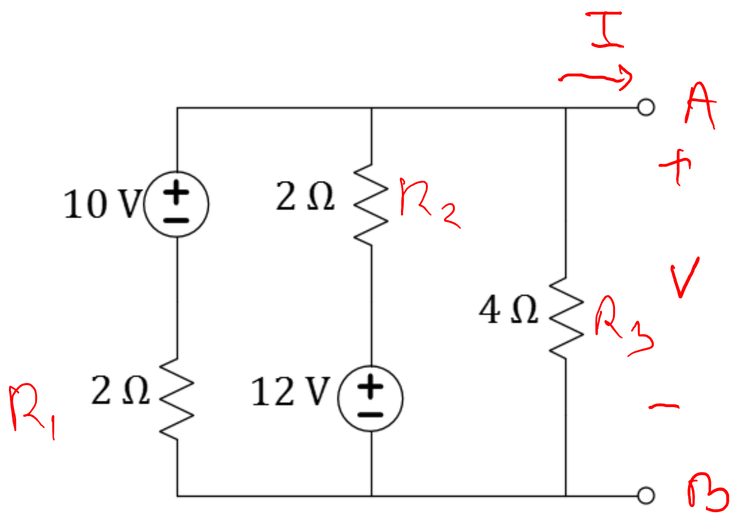


$I_n = \frac{V_T}{R_T}$

- Either can be used to represent universal: $\boxed{I = I_{sc} - \frac{I_{sc}}{V_{oc}} V}$
- Contain all information on how circuits interact with other circuits
- Loses information on power dissipation WITHIN the circuit

$\boxed{I = I_{sc} - R_{eff} \cdot V}$

Using Transformation to Find Equivalents



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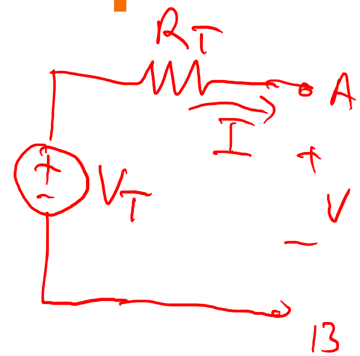


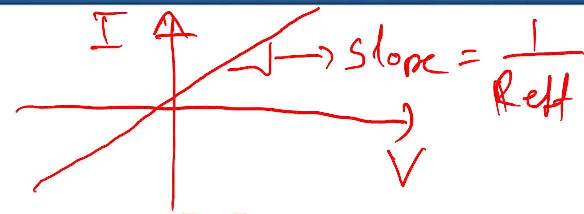
$I = f(V)$

$$R_T = \frac{1}{\frac{1}{R_1+R_2} + \frac{1}{R_3}}$$

$V_T = ?$

L10Q1: What is the Thevenin equivalent of the circuit above?

$V = 0$
$I = 0$

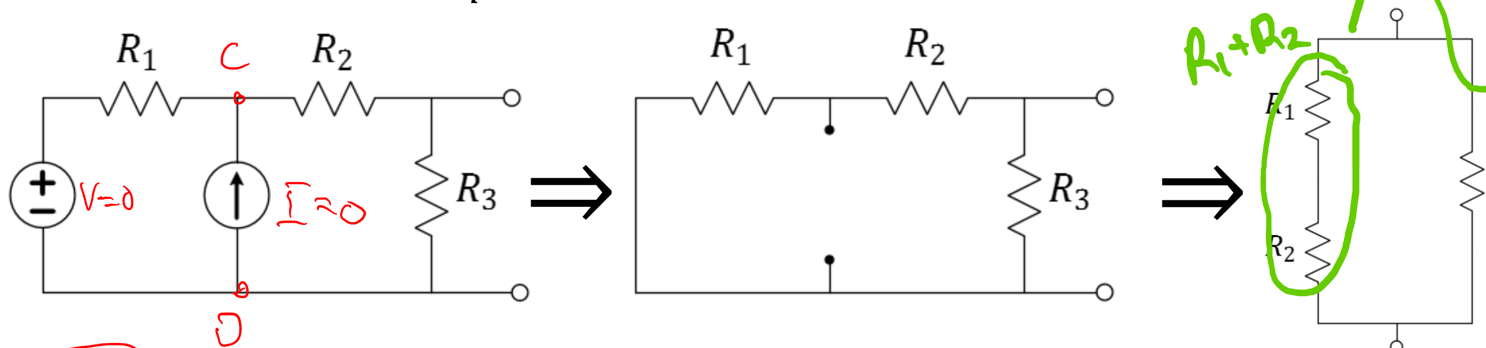


R_{eff} = R_T = R_N is R_{eq} with sources removed

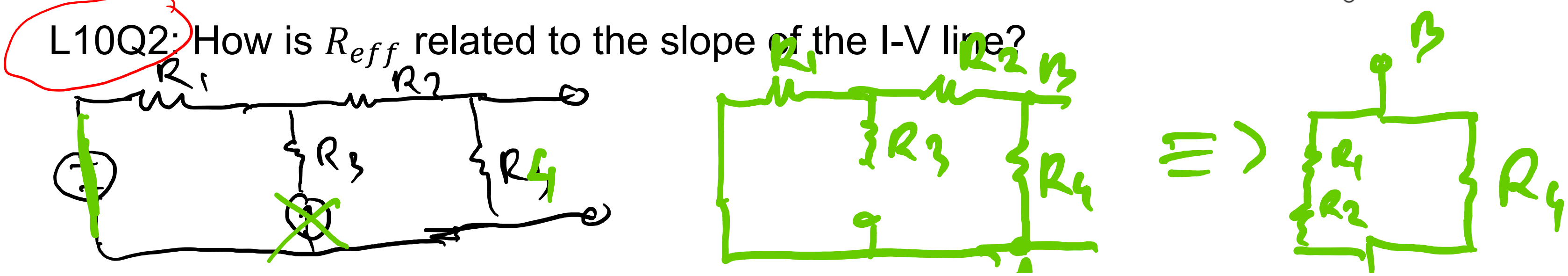
1. Short-circuit all voltage sources (i.e. set them to zero)
2. Open-circuit all current sources (i.e. set them to zero)
3. Find resulting R_{eq} using parallel and series relationships

$R_{eq} = (R_1 + R_2) \,||\, R_3$

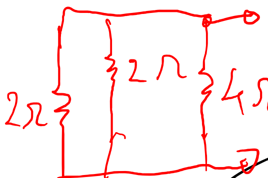
$\frac{1}{R_{eq}} = \frac{1}{R_1 + R_2} + \frac{1}{R_3}$

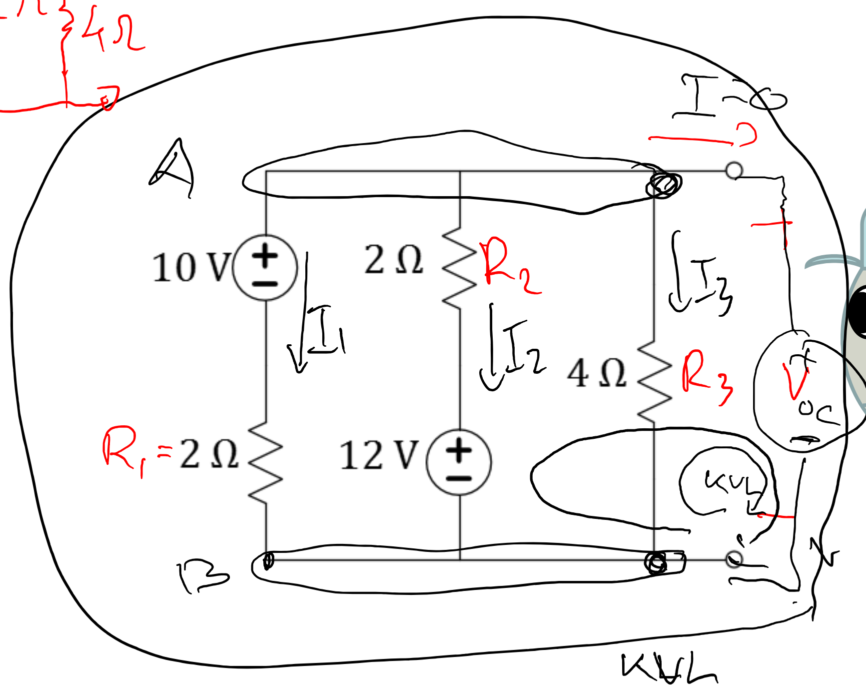


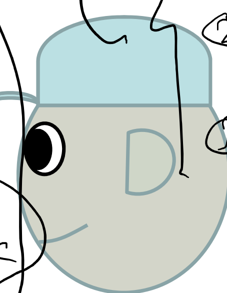
L10Q2: How is R_{eff} related to the slope of the I-V line?



Finding R_{eff} is easy in multi-source circuits







$$⑤\ I_1 + I_2 + I_3 = 0$$

$$① \text{ KVL: } -R_3 I_3 + V_{oc} = 0 \Rightarrow I_3 = \frac{V_{oc}}{R_3}$$

$$② \text{ KVL: } -12V - 2I_2 + V_{oc} = 0 \Rightarrow I_2 = \frac{V_{oc}}{2} - 6$$

$$③ \text{ KVL: } -2I_1 - 10 + V_{oc} = 0 \Rightarrow I_1 = \frac{V_{oc}}{2} - 5$$

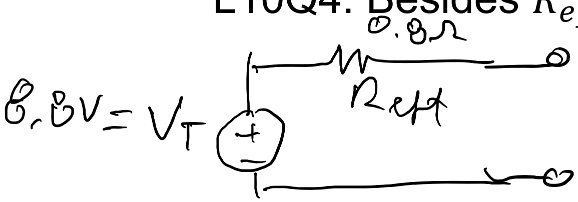
A. 8 Ω
B. 5 Ω
C. 4 Ω
D. 2 Ω
E. 0.8 Ω

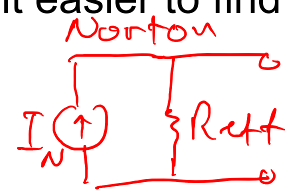
$$\boxed{V_{oc} = 8.8\ V}$$

$$R_{eff} = \frac{1}{\frac{1}{2} + \frac{1}{2} + \frac{1}{4}} = \boxed{0.8\ \Omega}$$

L10Q3: What is R_{eff}, for the circuit above?

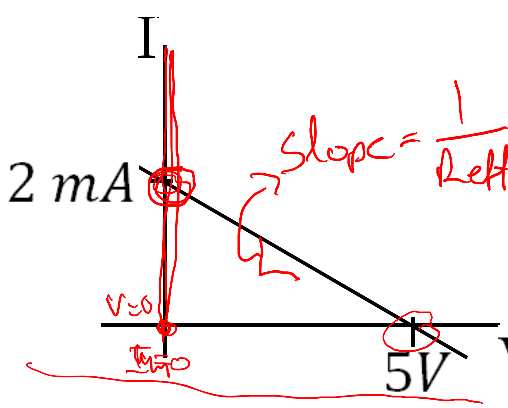
L10Q4: Besides R_{eff}, is it easier to find I_{SC} or V_{OC}?

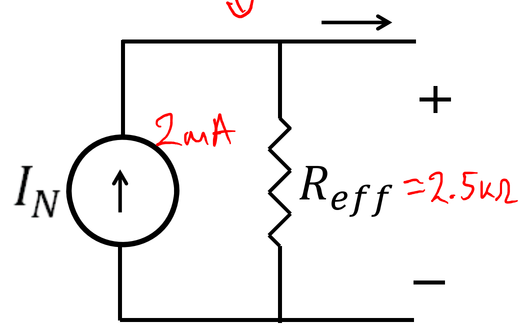


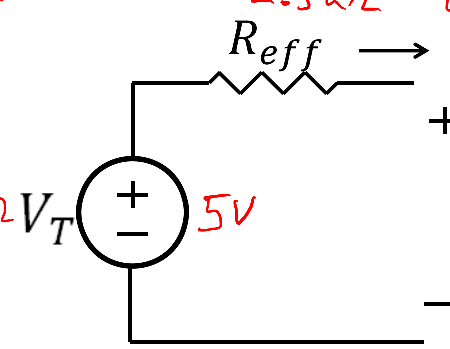


$$I_N = I_{SC} = \frac{V_{oc}}{R_{eff}} = \frac{8.8V}{0.8\Omega} = \boxed{11A}$$

One can find a circuit given a line







$I = f(V)$

$I_{sc} = ?$ $V=0$

$\Rightarrow I_{sc} = 2mA$

L10Q5: What is R_{eff}, for the circuit with the given I-V line?

$$R_{eff} = \frac{V_{oc}}{I_{sc}} = \frac{5V}{2mA} = 2.5\,k\Omega$$

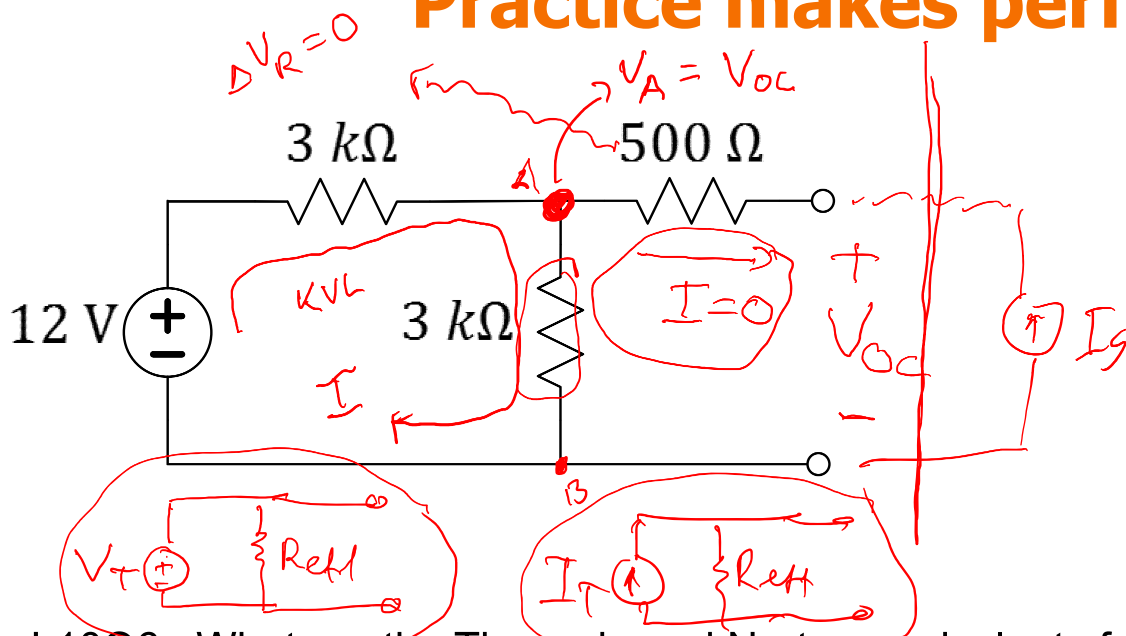
$V_{oc} = ?$ $I=0$

$\Rightarrow V_{oc} = 5V$

$I_N = I_{sc} = 2mA$

$V_T = V_{oc} = 5V$

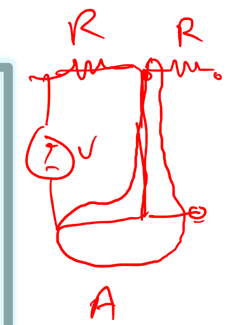
Practice makes perfect!



In History…

Leon Charles Thevenin was a telegraph engineer. In 1883, his theorem expanded modelling of circuits and simplified circuit analysis based on Ohm's Law and Kirchhoff's Laws.

The dual "Norton's theorem" didn't arrive until 1926 with the efforts of Bell Labs engineer, **Edward Lawry Norton**.



L10Q6: What are the Thevenin and Norton equivalents for the circuit above?

$R_{eff} = ?$

$V = 0 \quad I = 0$

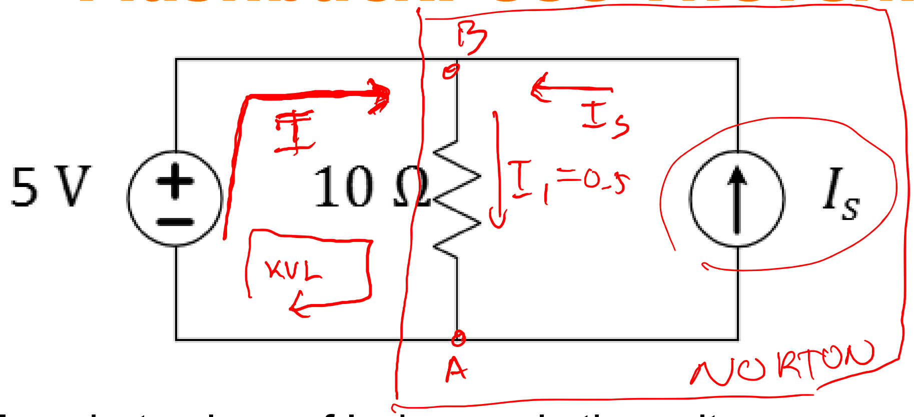
$$R_{eff} = (3k \,//\, 3k) + 500 = \frac{1}{\frac{1}{3}+\frac{1}{3}} + 500 = 1.5k\Omega + 0.5k\Omega = \boxed{2k\Omega}$$

$$V_T = V_{OC} = V_A = 12\,\frac{3}{3+3} = 6V$$

$$\boxed{V_T = 6V}$$

$$\boxed{I_N = \frac{V_T}{R_{eff}} = \frac{6V}{2k} = 3mA}$$

Flashback! Use Thevenin to solve.



node B KCL: $I_1 = I + I_s$

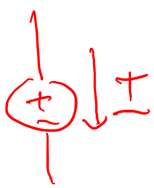
$-5V + 10\cdot I_1 = 0$

$\boxed{I_1 = 0.5A}$

$I_s = I_1 - I = 0.5A - I$

Q7: For what values of I_s does only the voltage source supply power?

$\boxed{I > 0}$

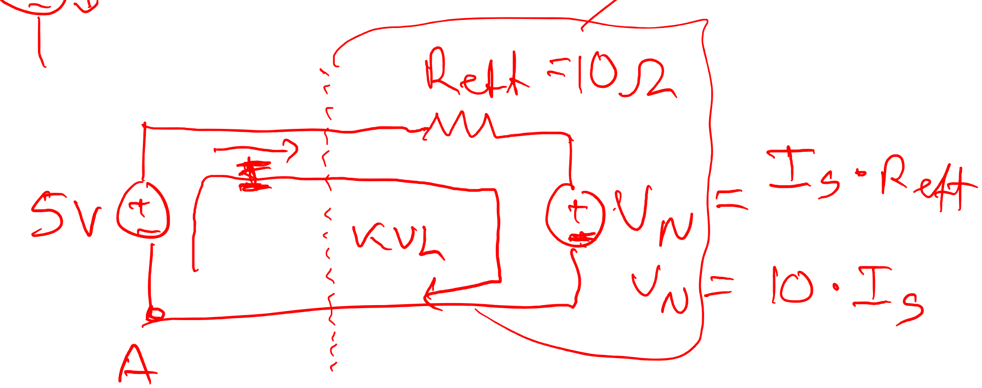


$\boxed{I < 0}$

$I_s = 0.5 - I$

$I = 0.5 - I_s > 0$

$\boxed{I_s < 0.5A}$



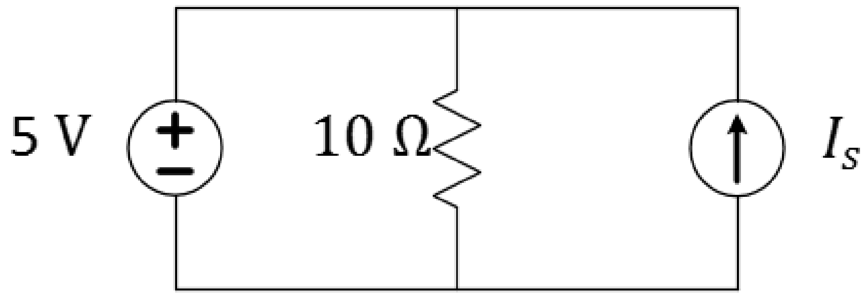
$-5V + R_{eff}\cdot I + V_N = 0$

$-5V + 10\cdot I + 10 I_s = 0$

$I = 0.5 - I_s > 0$

$\Rightarrow \boxed{I_s < 0.5A}$

Flashback! Use Thevenin to solve.



Q7: For what values of I_s does only the voltage source supply power?

Summary

- Any linear network can be represented by a simple series Thévenin circuit or, equivalently, by a simple parallel Norton circuit

- There are several methods for determining the quantities and depending on what is given about the original circuit

- It is the same resistance, R_{eff}, value for both the Thévenin and the Norton circuits, found as R_{eq} with the sources removed (SC for V-sources, OC for I-sources)

L10 Learning Objectives

a. Represent *any* (non-horizontal) linear IV characteristic by a series combination of a voltage source and a resistor (Thévenin equivalent circuit).

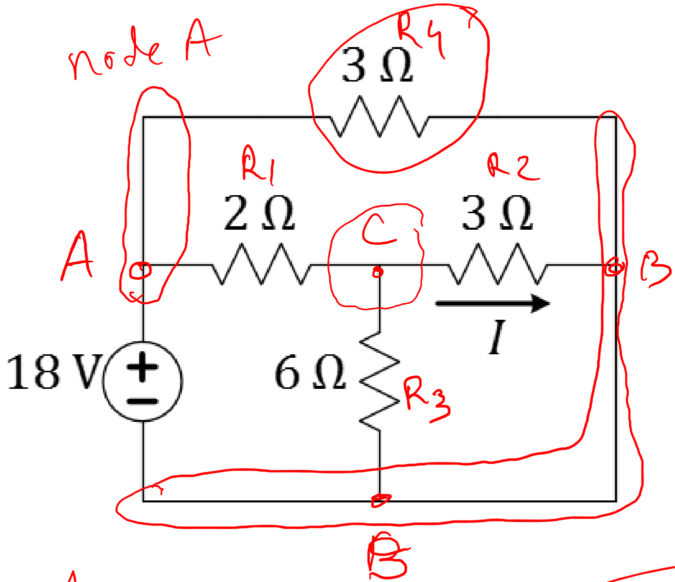
b. Represent *any* (non-vertical) linear IV characteristic by a parallel combination of a current source and a resistor (Norton equivalent circuit).

c. Find the parameters of Thévenin and Norton equivalent circuits, R_{eff}, V_T, and I_N when given a circuit.

Lecture 11: Node Method For Circuit Analysis

- Review of circuit-solving strategies
- Node Method steps
- Practice with the Node Method

What are the possible strategies to find *I*?



L11Q1: Is one of the resistors in parallel with the voltage source? If so, which?

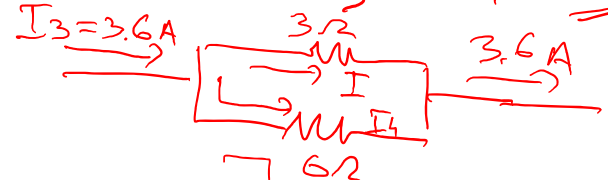
L11Q2: What is the value of the labeled current? $I = ?$

node A KCL: $I_1 = I_2 + I_3$

KVL: $I_2 = \frac{18}{3\Omega} = 6A$

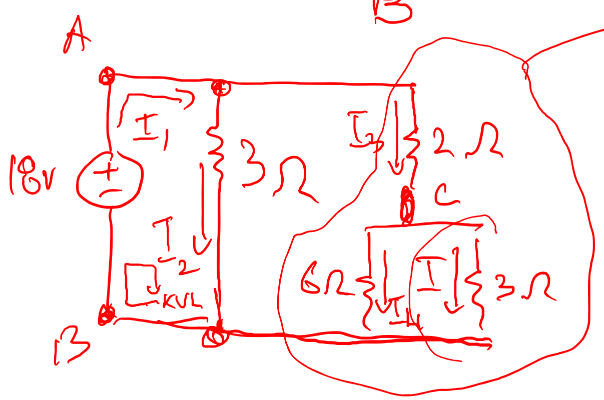
node C KCL: $I_3 = I_4 + I$

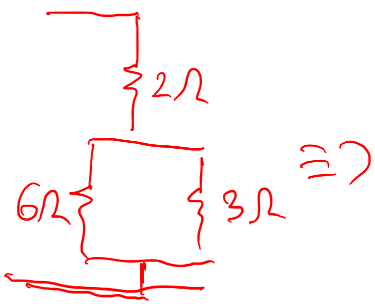
current divider circuit



$I = 4.5 \frac{6\Omega}{3\Omega + 6\Omega}$

$\boxed{I = 3A}$

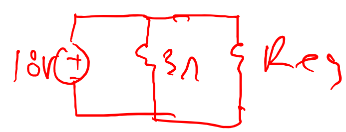




5Ω

$R_{eq} = 2\Omega + \frac{1}{\frac{1}{6} + \frac{1}{3}} = 4\Omega$

$\boxed{I_3 = \frac{18V}{4\Omega} = 4.5A}$



The Node Method

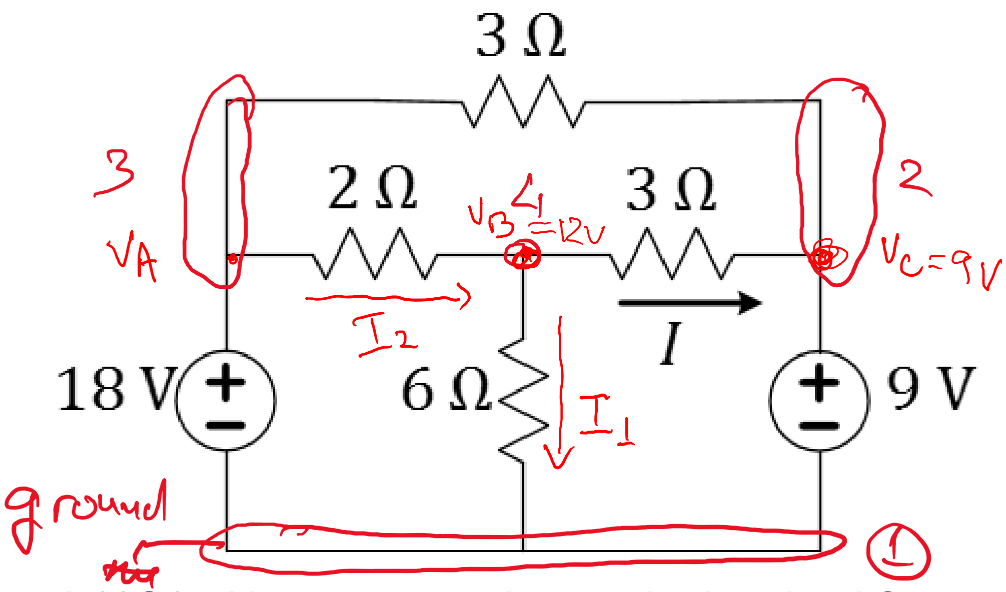
1. Identify or pick "ground" (0 V reference)

2. Label all the node voltages
   (use values when you can; variables when you must)

3. Use KCL at convenient node(s)/supernode(s)

4. Use voltages to find the currents

Node method is a good strategy for this problem because it contains two sources



$V_A = 18V$ $\quad V_B = ?$

$V_C = 9V$

$$I = \frac{V_B - V_C}{3\Omega} = \frac{V_B - 9V}{3\Omega}$$

KCL @ 4

$$I_2 = I + I_1$$

$$\left(\frac{V_A - V_B}{2\Omega}\right) = \left(\frac{V_B - V_C}{3\Omega}\right) + \left(\frac{V_B - 0}{6\Omega}\right)$$

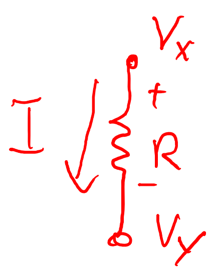
$$\frac{18 - V_B}{2} = \frac{V_B - 9}{3} + \frac{V_B}{6}$$

$$\boxed{V_B = 12\,V}$$

$$I = \frac{V_B - V_C}{3} = \frac{12 - 9}{3} = 1A$$

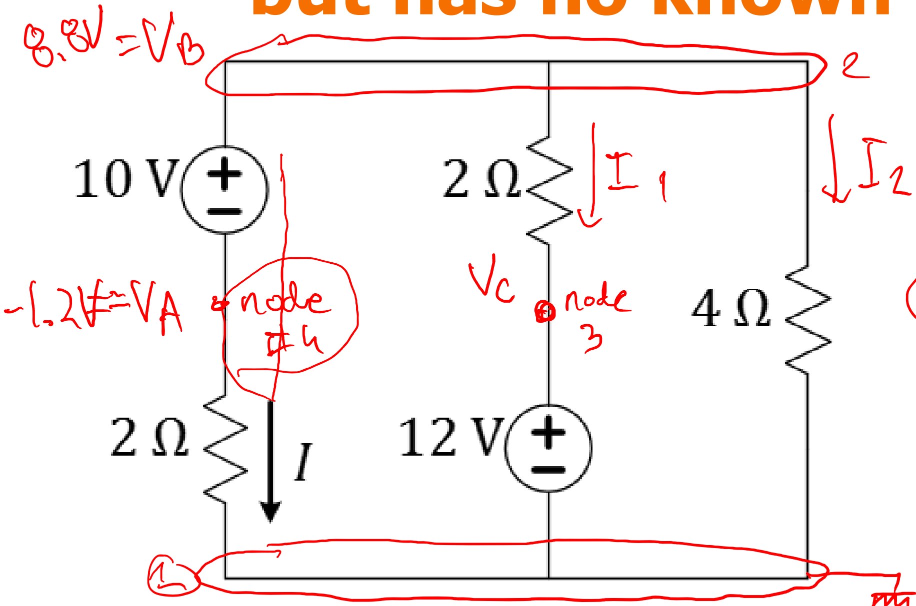
L11Q3: How many nodes are in the circuit?
L11Q4: What is the value of the labeled current?

A. 1
B. 2
C. 3
D. 4
E. 5



$$I = \frac{V_x - V_y}{R}$$

A *floating* voltage source: relates two nodes but has no known relationship to ground



$V_C = 12V$

$V_A, V_B = ?$

$V_B = 10 + V_A$

(2) $V_B - V_A = 10V$

KCL @ node#2

$I + I_1 + I_2 = 0$

$$\left(\frac{V_A}{2\Omega}\right) + \left(\frac{V_B - V_C}{2\Omega}\right) + \left(\frac{V_B - 0}{4\Omega}\right) = 0$$

(1) $\frac{V_A}{2\Omega} + \frac{V_B - 12}{2} + \frac{V_B}{4\Omega} = 0$

(2) $V_B - V_A = 10V$

$$\boxed{V_B = 8.8V \quad V_A = -1.2V}$$

L11Q5: How many nodes are in the circuit?
L11Q6: What is the value of the labeled current?

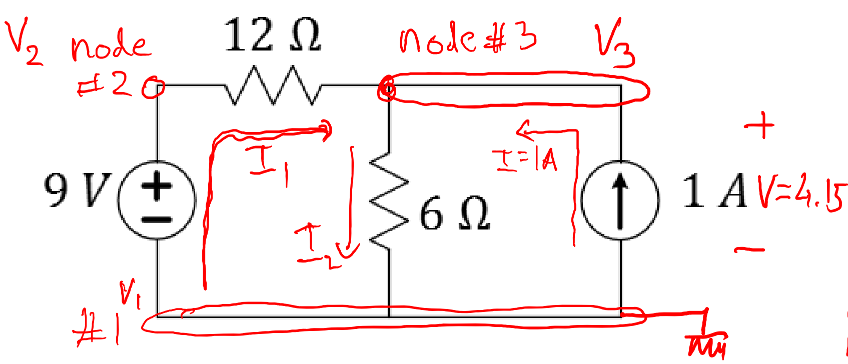
A. 1
B. 2
C. 3
D. 4
E. 5

ground

$$I = \frac{V_A - 0}{2\Omega} = \frac{-1.2V}{2\Omega} = -0.6A$$

$$\boxed{I = -0.6A}$$

Voltage across a current source is unknown



$V_1 = 0$

$V_2 = 9V$

$V_3 = ?$

KCL @ #3

$I_1 + I = I_2$

$$\frac{V_2 - V_3}{12} + (1A) = \frac{V_3 - V_1}{6\Omega}$$

$$\frac{9V - V_3}{12} + 1A = \frac{V_3 - 0}{6\Omega}$$

$$\boxed{V_3 = 4.15V}$$

$$I_1 = \frac{V_2 - V_3}{12} = \frac{9V - 4.15V}{12} = \ldots$$

$$I_2 = \frac{V_3}{6\Omega} = \frac{4.15}{12} = \ldots$$

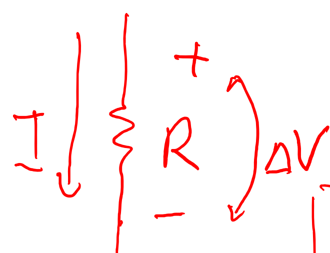
L11Q7: What is the power supplied or consumed by each element?

$$P_{(1A)} = -V_3 \cdot I = -4.15W$$

$$P_{6\Omega} = \frac{V_3^2}{R} = \frac{(4.15)^2}{6\Omega} = \cancel{\ldots}$$

$$P_{12\Omega} = \frac{\Delta V^2}{12\Omega} = \frac{(9-4.15)^2}{12\Omega} = \ldots$$

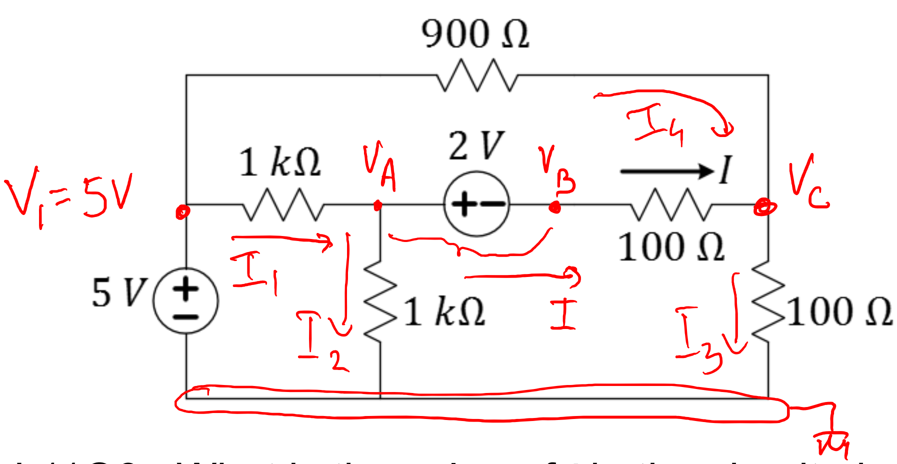
$$P_{9V} = -9V \cdot I_1 = -9V \cdot \left(\frac{9V - 4.15V}{12}\right) \ldots$$



$$\boxed{P = I \cdot V > 0}$$

$$\Sigma P = 0$$

Sometimes two or more node voltages are unknown (more challenging!)



$V_A, V_B, V_C = ?$ $\boxed{V_1 = 5V}$

(1) $V_A - V_B = 2V$

KCL @ A

$I_1 = I_2 + I$

(2) $\frac{V_1 - V_A}{1k\Omega} = \frac{V_A - 0}{1k\Omega} + \frac{V_B - V_C}{100\Omega}$

L11Q8: What is the value of *I* in the circuit above?

KCL @ C

$I + I_4 = I_3$

(3) $\left(\frac{V_B - V_C}{100\Omega}\right) + \left(\frac{V_1 - V_C}{900\Omega}\right) = \frac{V_C - 0}{100\Omega}$

$V_A = ?$ $V_C = ?$

$V_B = V_A - 2V$

$\boxed{I = \frac{V_B - V_C}{100\Omega}}$

L11 Learning Objectives

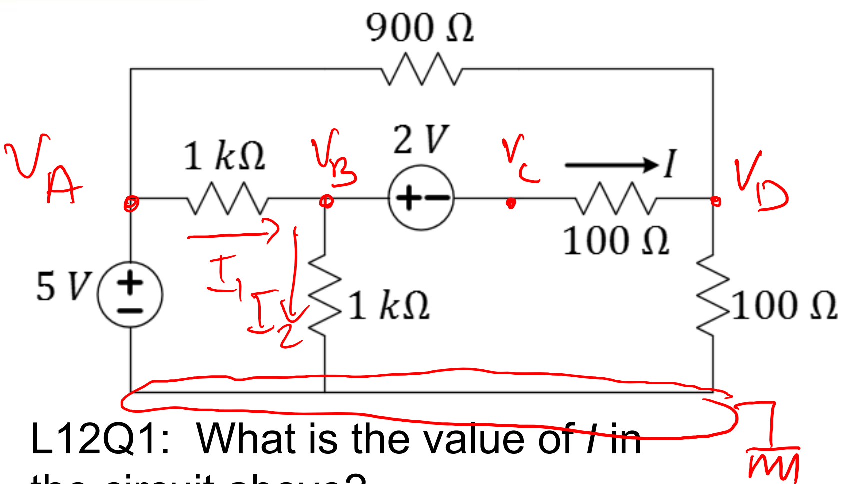
a. Outline (list, describe) steps of the Node Method

b. Use these steps to speed the process of performing circuit analysis via KCL/KVL/Ohm's

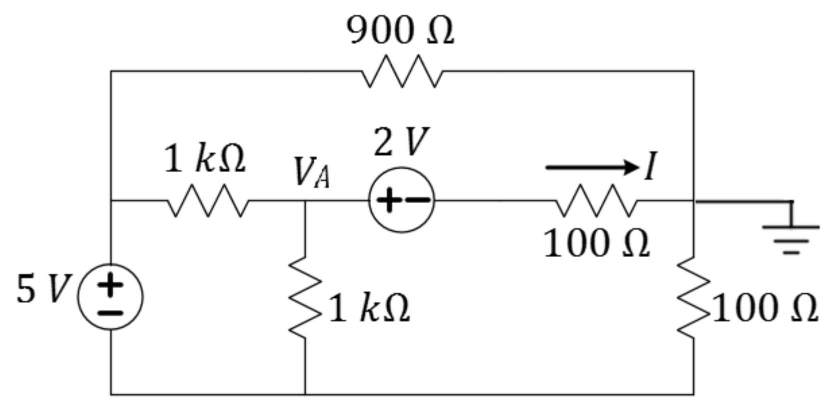
c. Identify circuit patterns in which different techniques might simplify the process of finding a solution (Practice!)

Lecture 12: Exercises

- We will use this lecture to catch up, if needed
- We will also do more exercises on recent topics
- Slides may be distributed in lecture



L12Q1: What is the value of *I* in the circuit above?



L12Q2: What is the value of V_A in the circuit above?

$V_A = 5V$

$V_C = V_B - 2V$

KCL B

$I + I_2 = I_1$

$$\frac{V_C - V_D}{100} + \frac{V_B}{1k\Omega} = \frac{V_A - V_B}{1k\Omega}$$

$$\boxed{\begin{aligned} V_B &= 2.13V \\ V_D &= 0.56V \end{aligned}}$$

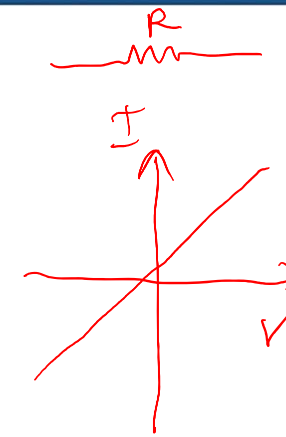
$$\boxed{I = -4.3\,mA}$$

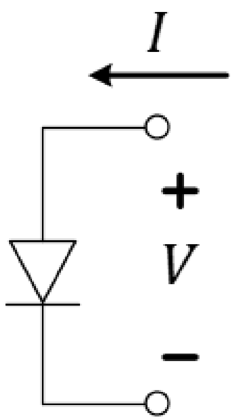
Lecture 13: Introduction to Diodes

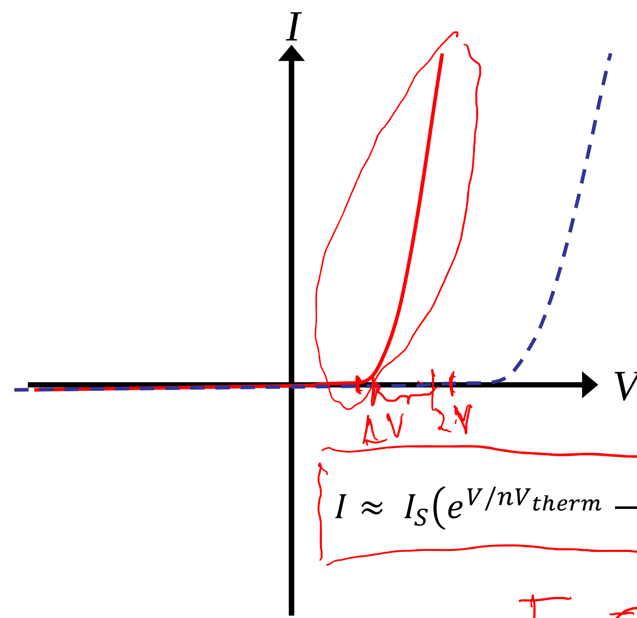
- Diode IV characteristics
- Connecting diode to a linear circuit
- Piecewise linear models of diodes

Recommended: https://learn.sparkfun.com/tutorials/diodes

Diode as a two-terminal device







$$\boxed{I \approx I_S\left(e^{V/nV_{therm}} - 1\right)}$$

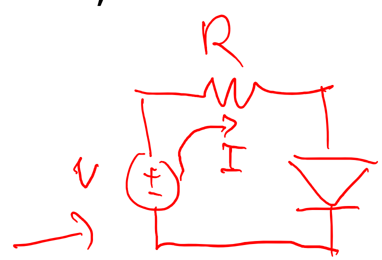
$$I \approx e^{V/V_T}$$

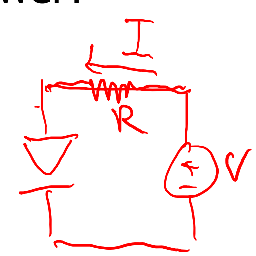
Made out of *semiconductor* materials like Si, Ge, AlGaAs, GaN with some additives called *dopants.*

Major applications: lighting, electronics

L13Q1: Based on the exponential equation for IV, can the diode supply power?

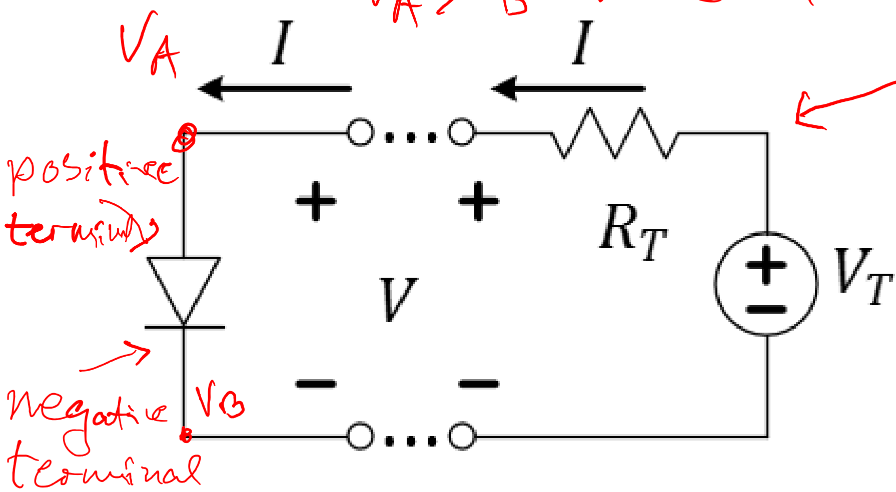
$\boxed{\text{NO}}$

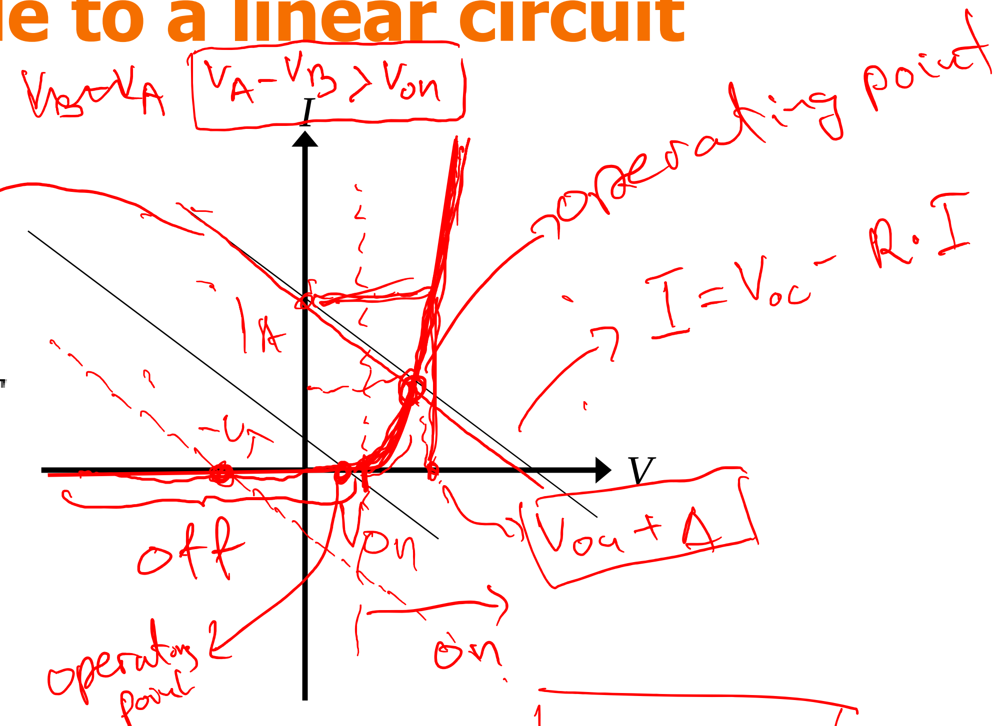




Connecting diode to a linear circuit

$V_A > V_B$ diode on $V_B < V_A$ $\boxed{V_A - V_B > V_{on}}$





We can solve graphically for an operating point.
For an LED more current means more light.

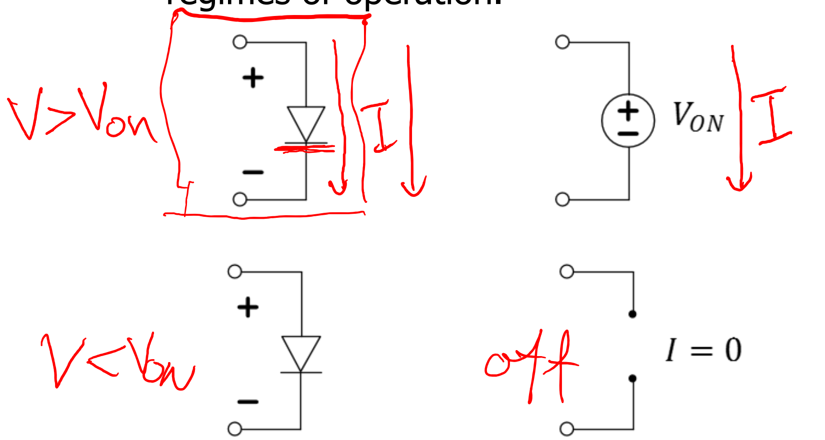
L13Q2: What is the current flowing through the diode if $V_T < 0$?

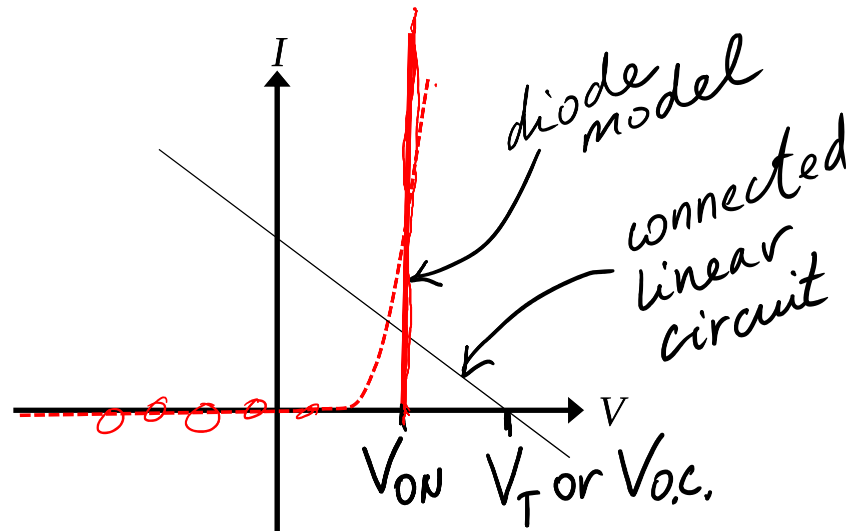
$\boxed{I = 0}$

$V_B > V_A$ diode is off

Modeling diode with linear IV segments

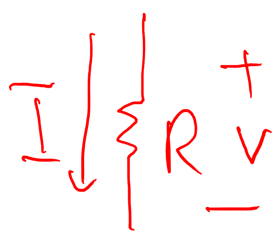
Instead of looking for graphical solutions, we can approximate the diode with two line segments, corresponding to diode's regimes of operation.



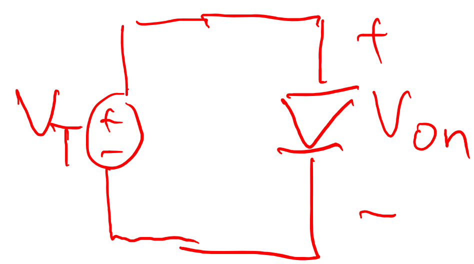


L13Q3: What is the minimum V_T of the connected linear circuit which causes current to flow through the diode if the piecewise linear model above is used?

$V_{T,min} = V_{on}$



$P = V \cdot I$



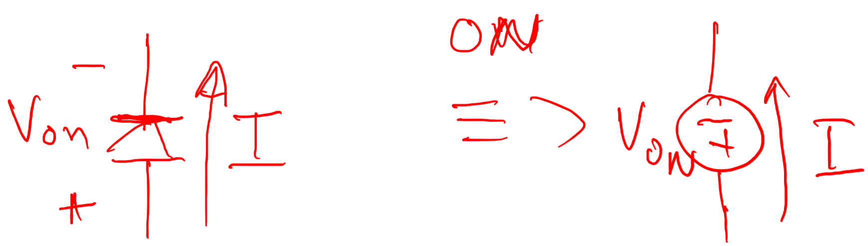
$V_{on} \approx \boxed{0.5V \text{ to } 0.7V}$

Different diode types have different V_{ON}

Diode Type	V_{ON}(V)	Applications
Silicon	0.6-0.7	General; integrated circuits; switching, circuit protection, logic, rectification, etc.
Germanium	~0.3	Low-power, RF signal detectors
Schottky	0.15-0.4	Power-sensitive, high-speed switching, RF
Red LED (GaAs)	~2	Indicators, signs, color-changing lighting
Blue LED (GaN)	~3	Lighting, flashlights, indicators
"Ideal"	0	Can neglect V_{ON} for high voltage applications

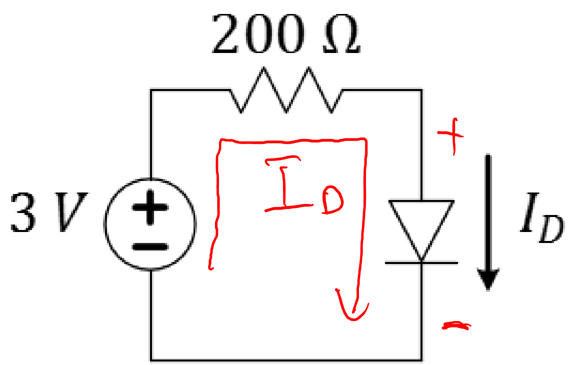
Q4:
A. 3 mW
B. 9 mW
C. 30 mW
D. 90 mW
E. 900 mW

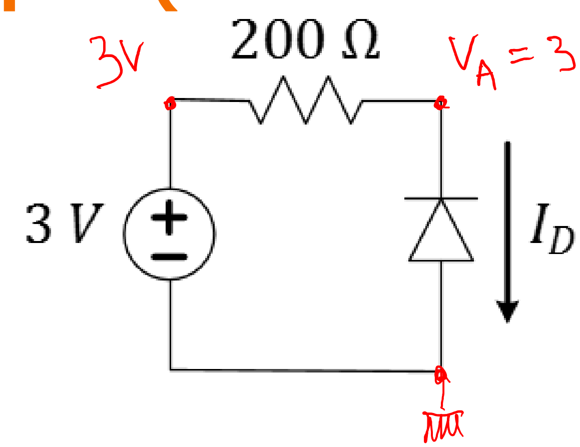
L13Q4: What is the power dissipated by a Ge diode if 30 mA is flowing through it?



$$P = V_{ON} \cdot I = (0.3\,V)\cdot(30\,mA) = 9\,mW$$

Diode circuit examples (offset ideal model)





$V_A = 3V - 200 \cdot I_D = 3V - 200 \cdot \frac{3.7}{200}$

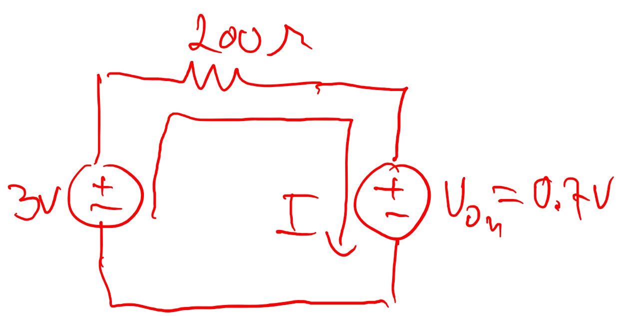
$\boxed{V_A = -0.7V}$

$\Rightarrow$ diode is off

$\boxed{I_D = 0A}$

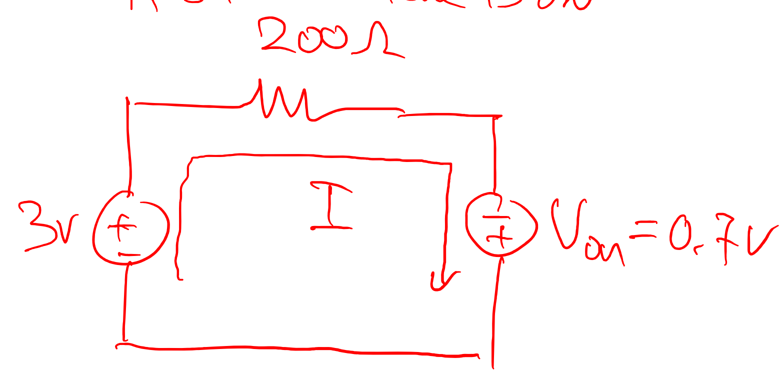
Assume offset-ideal model with V_{ON} = 0.7 (common Si diodes)
L13Q5: What is the current through the diode in the top left circuit?
L13Q6: What is the current through the diode in the top right circuit?

if diode is ON



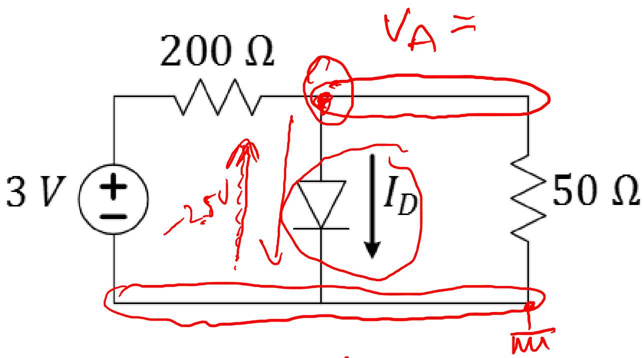
$$I = \frac{3 - 0.7V}{200\ \Omega} = 11.5\,mA$$

Assume diode is ON



$$I_D = \frac{3 - (-0.7)}{200\Omega} = \frac{3.7}{200\Omega}$$

Diode circuit examples (offset ideal model)



Assume offset-ideal model with V_{ON} = 0.7 (common Si diodes)

L13Q7: What is the current through the diode in the circuit?

$I_D =$

A. $-11.5\ mA$

B. $-2.5\ mA$

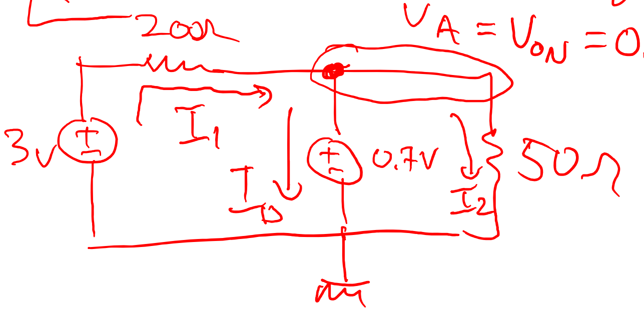
C. $0\ mA$

D. $+2.5\ mA$

E. $+11.5\ mA$

$\boxed{1^\circ}$ Assume the diode is ON. Prove $I_D > 0$

$V_A = V_{ON} = 0.7V$



KCL @ node A: $I_1 = I_D + I_2$

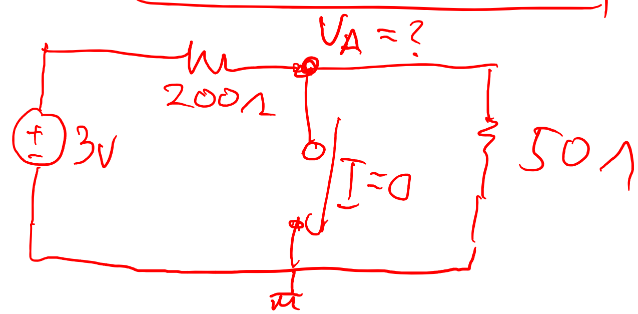
$$\frac{3V - 0.7V}{200\Omega} = I_D + \frac{0.7V}{50\Omega}$$

$$\boxed{I_D = -2.5\,mA}$$

$\boxed{2^\circ}$ diode is OFF ; => $V_A < V_{ON}$

$$\boxed{I_D = 0\,mA}$$

$V_A = ?$



$$V_A = 3V\,\frac{50\Omega}{200+50}$$

$$\boxed{V_A = 0.6V}$$

$V_A < V_{ON}$ ✓

L13 Learning Objectives

a. Draw a “typical” diode IV curve and describe its shape

b. Explain how to use graphical analysis to find the operating point of a diode connected to a linear circuit

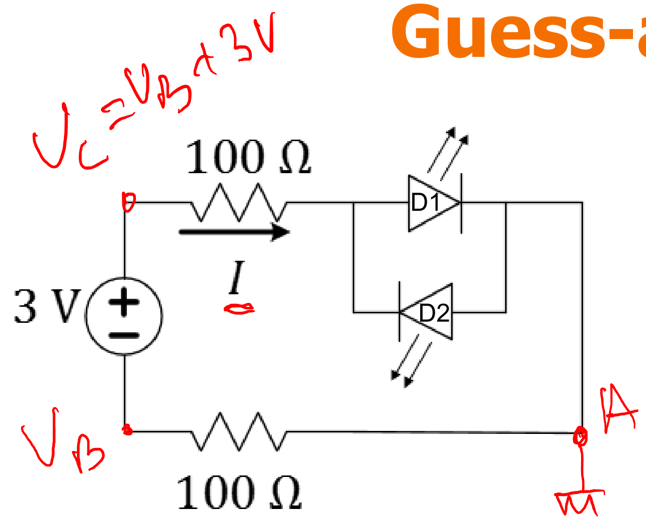
c. Describe the offset ideal diode model (open, V-source)

d. Solve simple circuit problems with one diode, given V_{ON}

Lecture 14: Diode Circuits

- Guess-and-check for diode circuits
- Current-limiting resistors and power dissipation
- Voltage-limiting (clipping) diode circuits

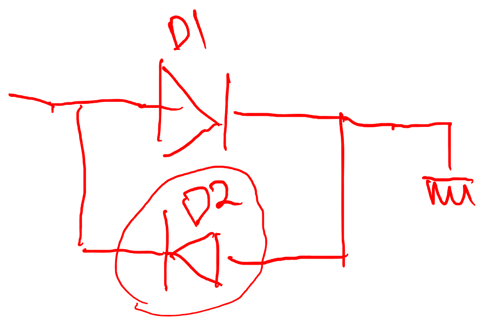
Guess-and-check example



Assume OIM with V_{ON} = 2 V (red LED)

L14Q1: What is the current supplied by the voltage source?

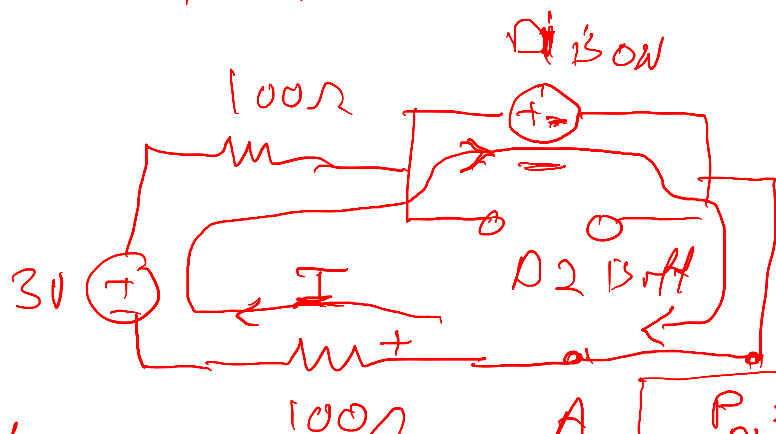
L14Q2: What is the power dissipated in each diode?



D1 is on

D2 is off

$$(I \cdot 100\Omega) - 3V + (I \cdot 100\Omega) + 2V = 0$$

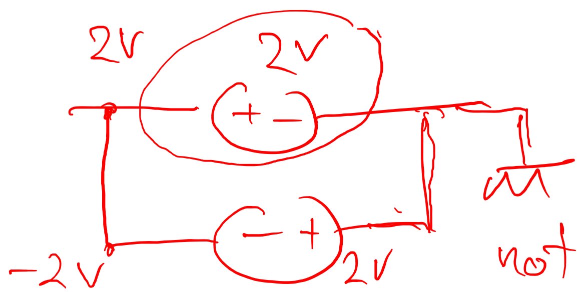


$$200 \cdot I = 1$$

$$I = \frac{1}{200} = 5mA$$

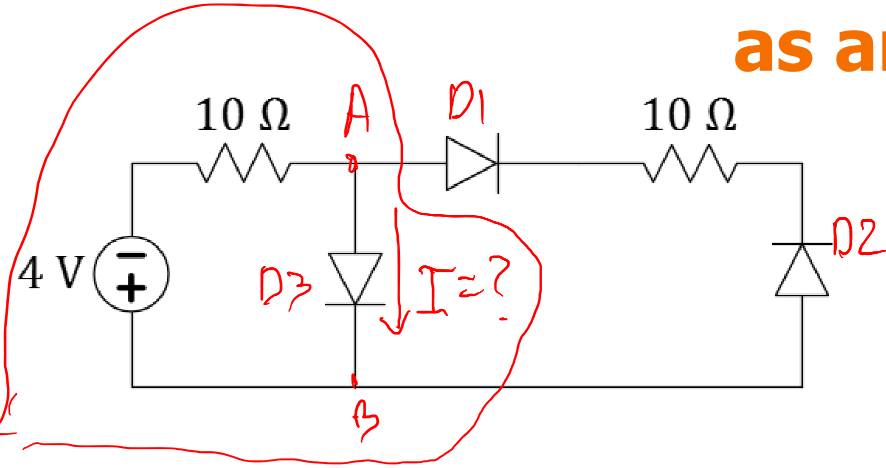
$P_{D1} = (2V) \cdot (5mA) = 10mW$

$P_{D2} = 0$



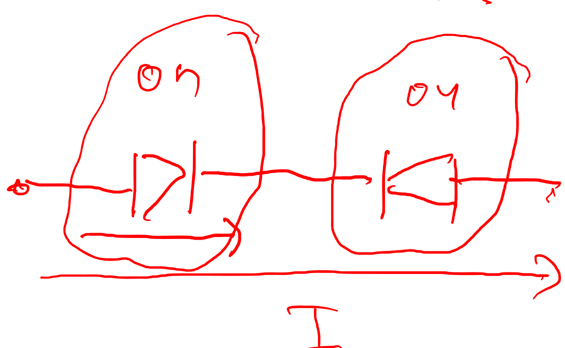
not possible

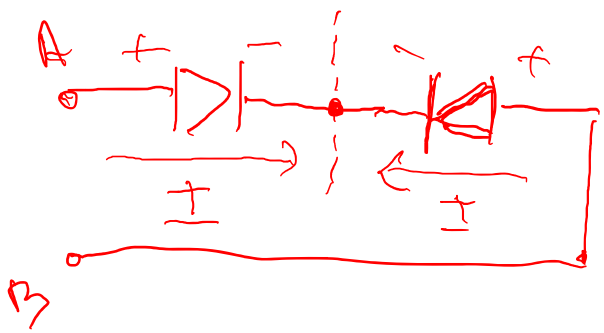
Back-to-back diodes in series are modeled by OIM as an open circuit



L14Q3: Assume OIM with V_{ON} = 0.7 V (Si) What is the current through the left-most diode?

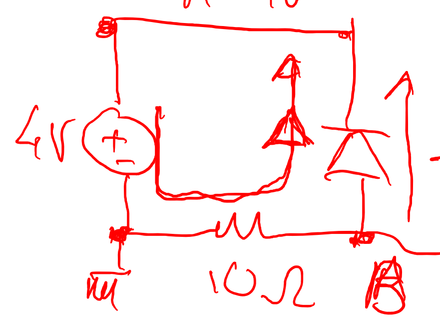
A. 0 *Amps*
B. 0.2 *Amps*
C. 0.33 *Amps*
D. 0.4 *Amps*
E. 3.3 *Amps*





$V_A = 4V$

Assume D3 is on



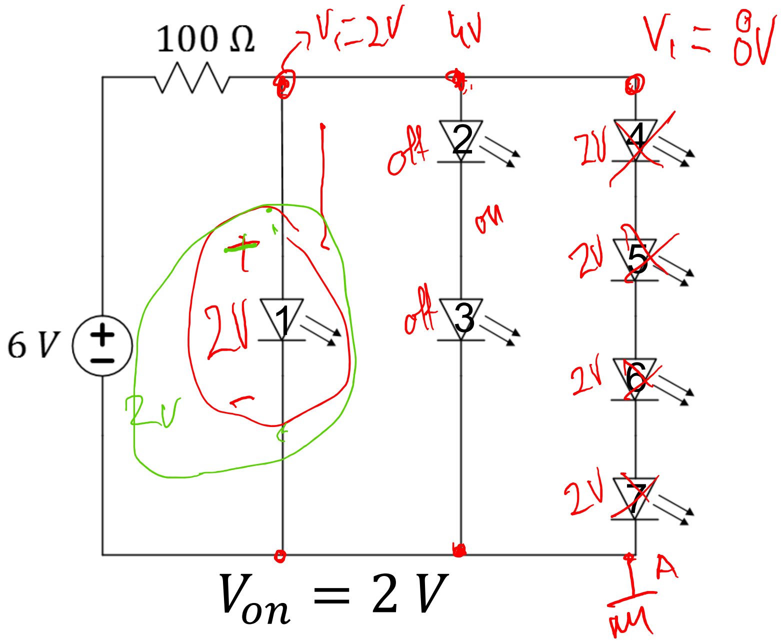
$V_B = 4.7V$

D1 & D2 ~~are~~ are <u>OFF</u>

D3 is <u>OFF</u>

$\boxed{I = 0A}$

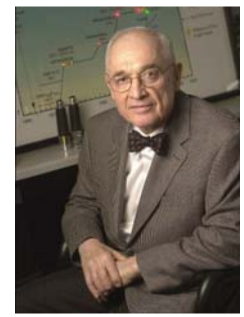
Another guess-and-check example



Q4:
A. 1
B. 3
C. 4
D. 7
E. other

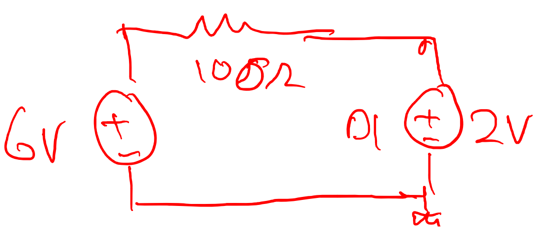
ECE Spotlight…

The first visible-light LED was developed by University of Illinois alumnus (and, later, professor) Nick Holonyak, Jr., while working at General Electric in 1962 with unconventional semiconductor materials.
He immediately predicted the widespread application of LED lighting in use today.

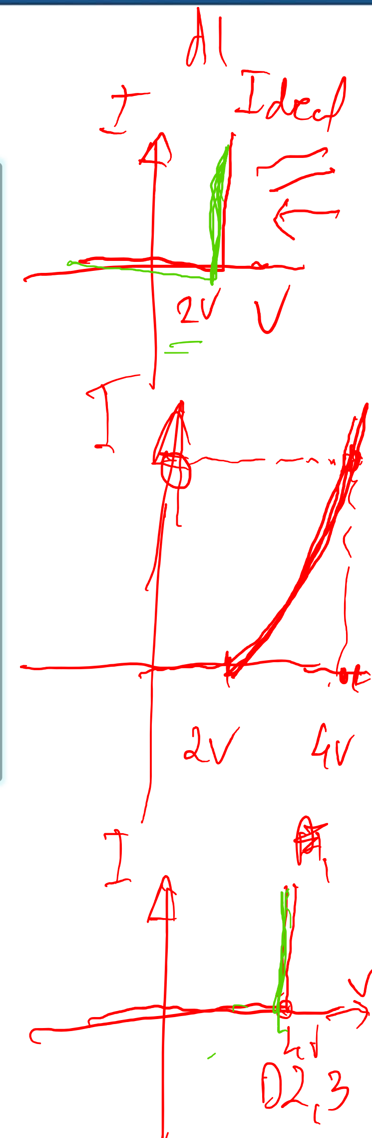


L14Q4: How many red LEDs are turned on in the circuit above? (Use OIM)

Diodes: 4,5,6,7 are off ; 2,3 are OFF

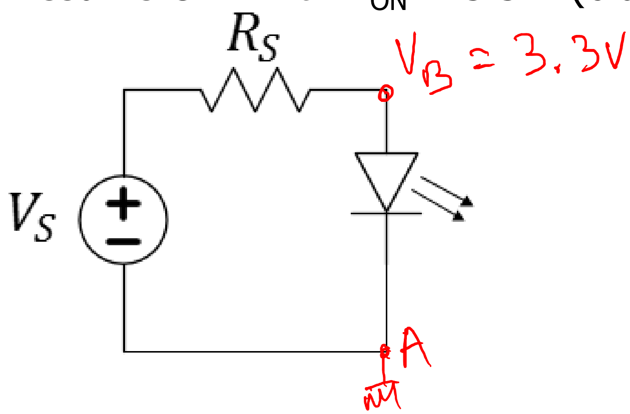


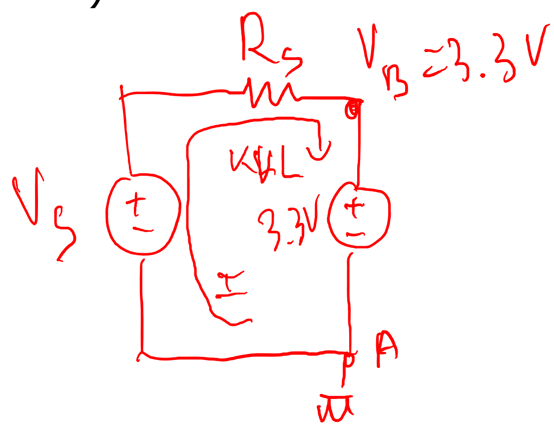
diode #1 is ON

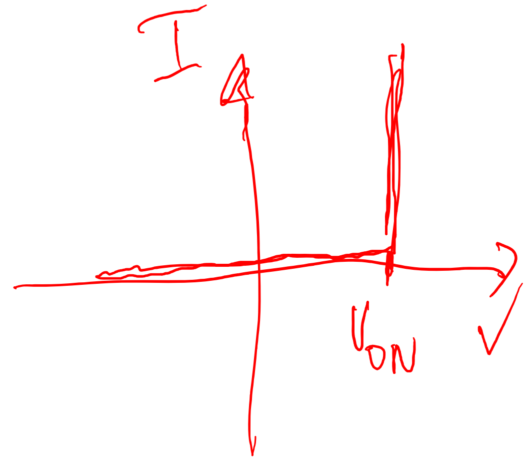


Current-limiting resistors for LEDs

Assume OIM with V_{ON} = 3.3 V (blue LED)







L14Q5: How many 1.5 V batteries are needed to turn on the LED?
L14Q6: What is the series resistance needed to get 16 mA through the LED?
L14Q7: What is the resulting power dissipation in the diode?

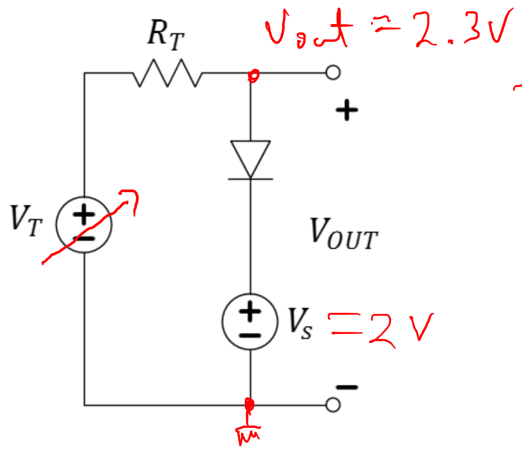
Q5 $N = 3$ $V_S = 4.5V > V_{on} = 3.3V$

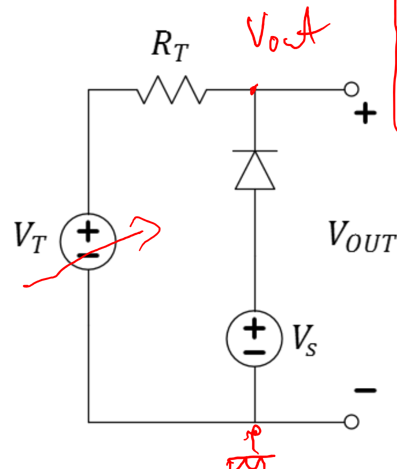
Q6 $I = \frac{V_S - V_B}{R_S}$ $R_S = \frac{V_S - V_B}{I} = \frac{(4.5V) - (3.3V)}{16mA} = 75\Omega$

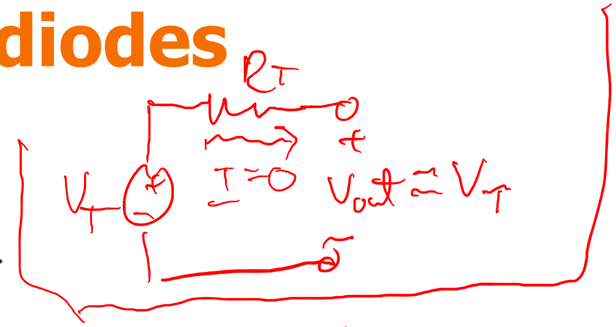
Q7 $P = (V_{on}) \cdot I = (3.3V) \cdot (16mA) = 52.8\, mW$

Setting voltage limits with diodes

Assume OIM model with V_{ON} = 0.3 V (Ge diode)

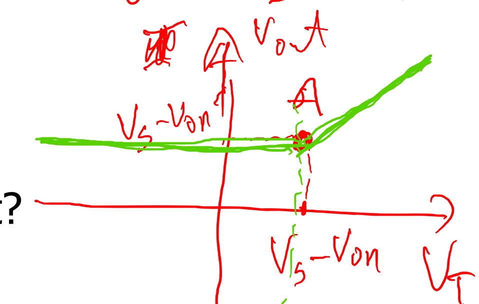




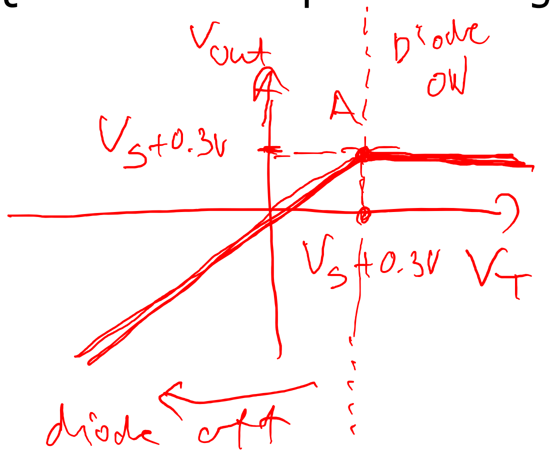


Q9 if diode is on

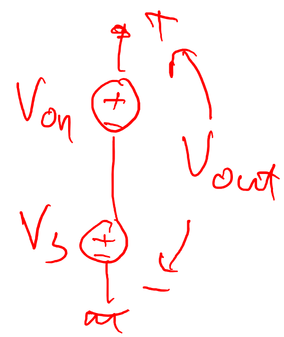
$V_{out} = V_s - V_{on}$



L14Q8: What is the possible range of the output voltages in the left circuit?
L14Q9: What is the possible range of the output voltages in the right circuit?



Q8 if diode is on



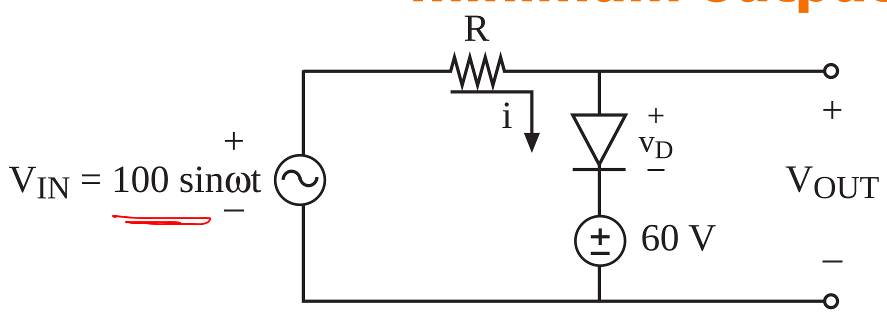
$V_{out} = V_s + V_{on}$

diode ON

diode off

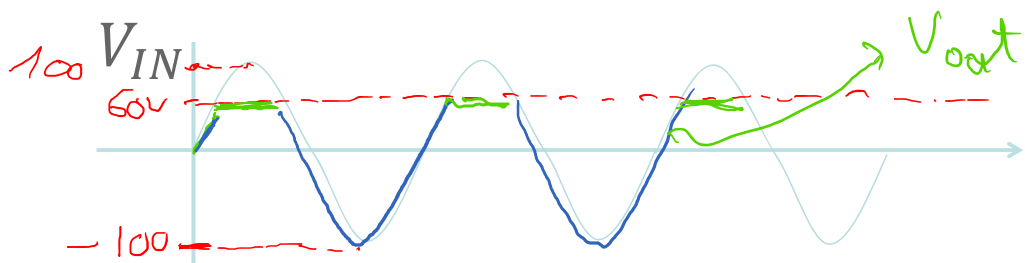
$V_{out} = V_T$

A voltage-clipping circuit sets maximum or minimum output voltage



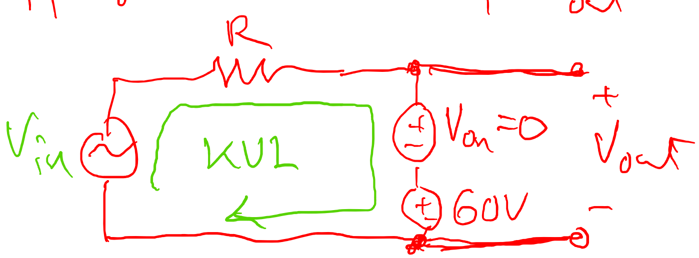
KVL:

$V_{OUT} = 60 + v_D$

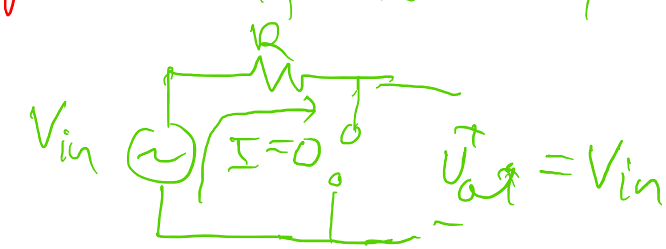


L14Q10: If the input voltage waveform is shown, what is the output waveform, assuming an ideal diode model (V_{ON} = 0 V)?

if diode is ON ; $V_{out} \approx 60V$; $V_{in} \geq 60V$



if $V_{in} < 60V$, diode is off

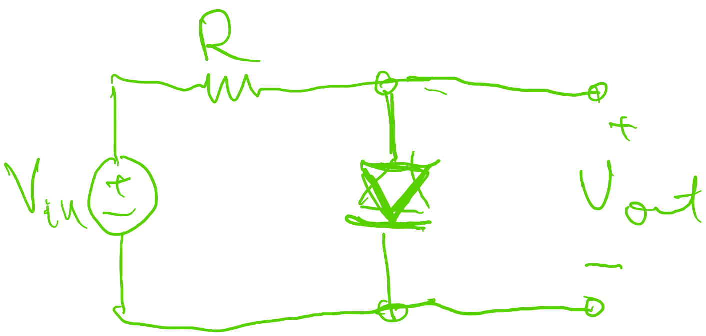


L14 Learning Objectives

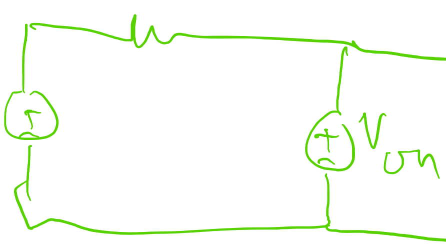
a. Solve circuit analysis problems involving sources, resistances, and diodes
b. Estimate power dissipation in diode circuits
c. Select appropriate current-limiting resistors
d. Determine voltage limits and waveforms at outputs of diode voltage-clipping circuits

Lecture 15: Exercises

- We will use this lecture to catch up, if needed
- We will also do multiple exercises
- Slides may be distributed in lecture

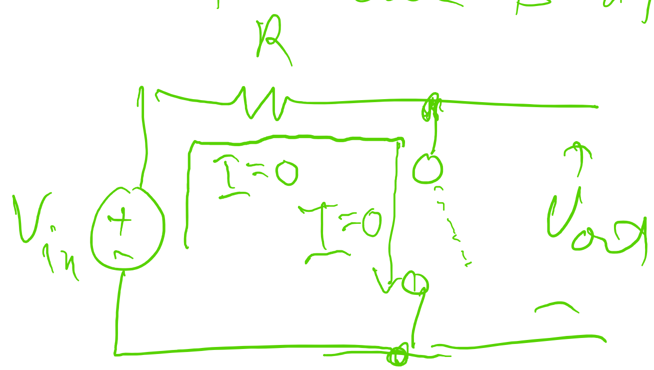


if diode is on ; $V_{in} \geq V_{on}$



$V_{out} = V_{on}$

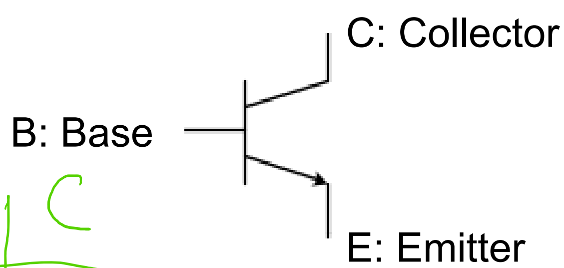
if diode is off

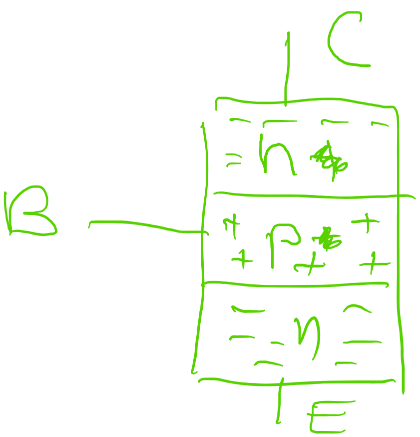


$V_{out} = V_{in} - \overset{0}{I} \cdot R = V_{in}$

L16: The Bipolar Junction Transistor (BJT)

- BJT is a controlled current source…
  - current amplifier
- The three operating regimes of a BJT
- Controlling a resistive load with a BJT
- Solving for saturation condition

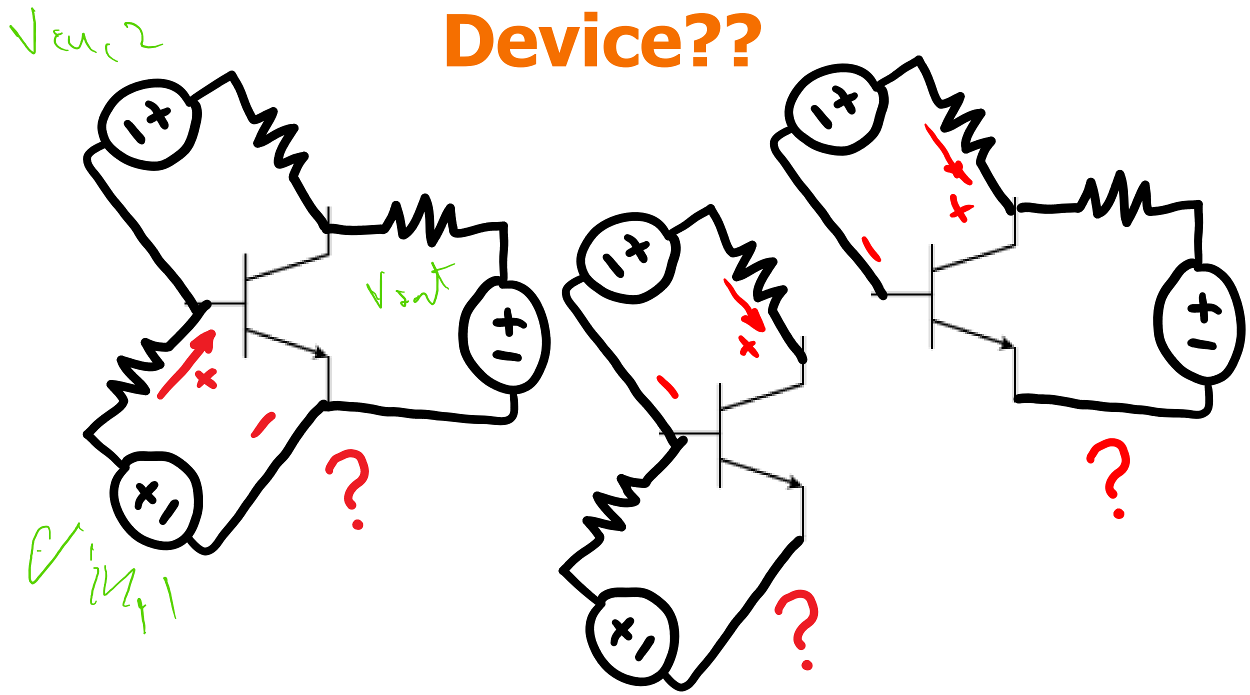




ECE Spotlight…

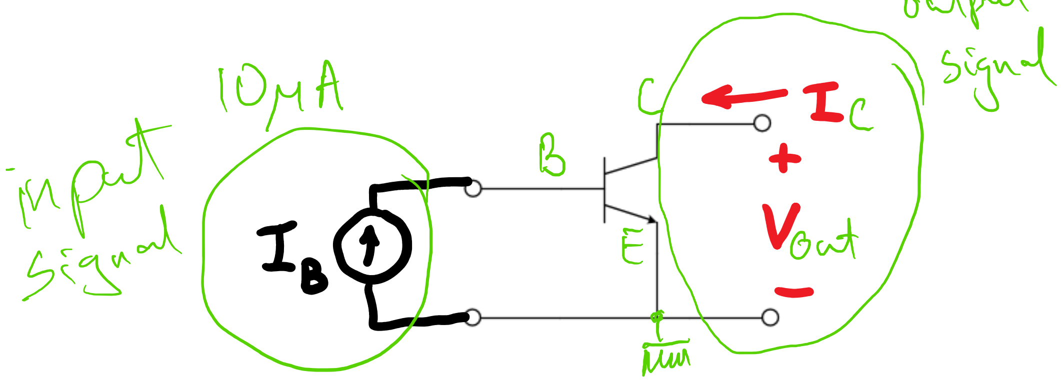
John Bardeen, the co-inventer of the transistor, was also the Ph.D. advisor at the University of Illinois for Nick Holonyak, Jr. of LED fame.

IV Characteristic of a 3-terminal Device??

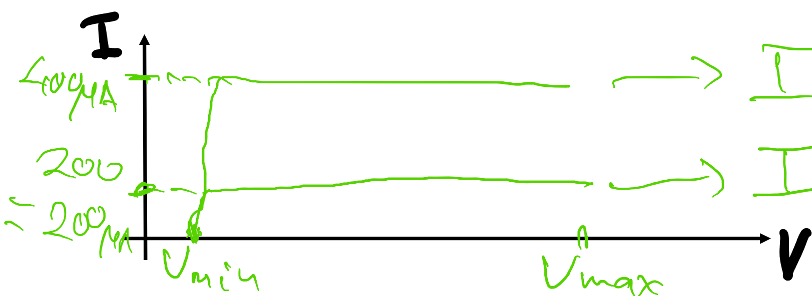


No single way to connect three-terminal device to a linear circuit.

ECE110 considers only the "common-emitter" configuration



If we fix I_B, we can measure the resulting I and V at the other side.



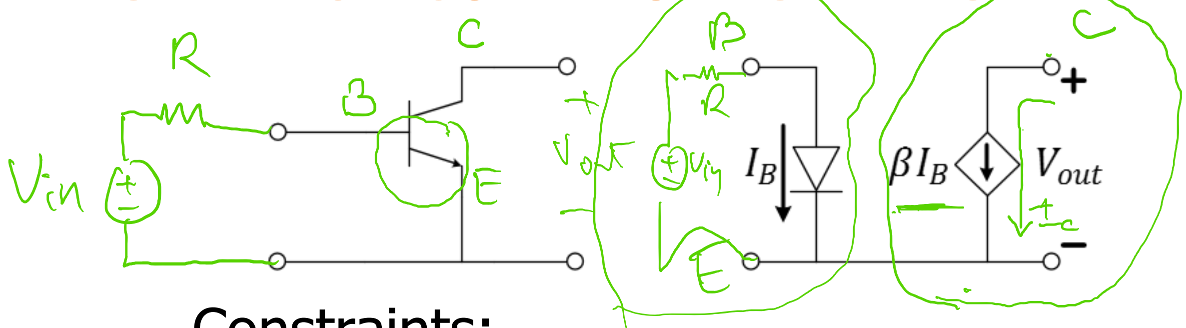
$I_{C2} = \beta I_{B2}$ $\quad$ $I_{B2} = 20\mu A$

$I_{B1} = 10\mu A$ $\quad$ $I_C = 200\mu A$ $\quad$ $I_{C1} = \beta I_{B1}$

$$\boxed{I_C = \beta \cdot I_B}$$

$\underline{\beta \approx 20}$

The BJT's "common-emitter NPN" model



$V_{on} = 0.5V$

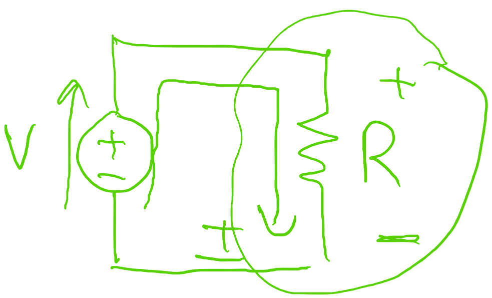
$V_{in,min} = 0.5V$

Constraints:

- Limited current range: $\beta I_B \geq 0$
- Limited voltage range: $V_{out} > 0$

L16Q1: Given these constraints, can this "dependent" current source deliver power?

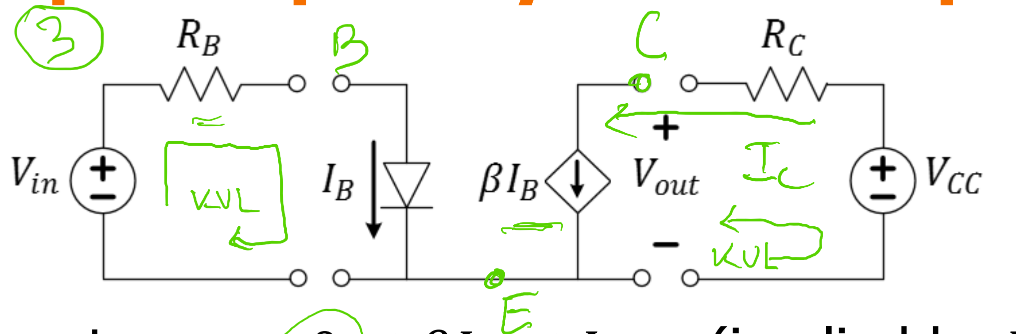
A. Yes, all current sources can supply power
B. No, this current source cannot supply power
C. Neither A or B is correct.



$P_{power\ supply} = -V \cdot I$ delivering power

R, $P_{resistor} = V \cdot I$ → consuming power

Two Loops Coupled by Current Equation



$I_C = \beta I_B$

Constraints:

- Limited current range: $0 \leq \beta I_B \leq I_{max}$ (implied by V_{min})
- Limited voltage range: $V_{out} \geq V_{min} \approx 0$

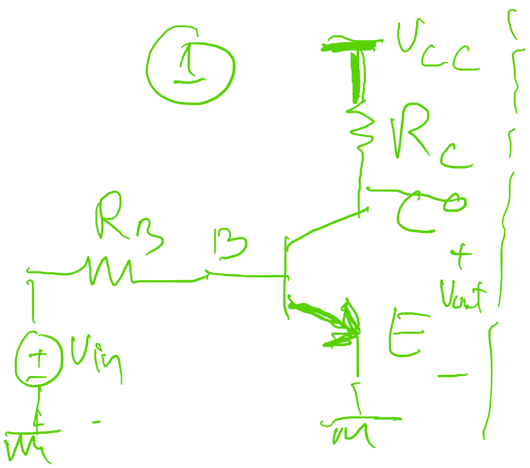
$I_B = \frac{V_{in} - V_{on}}{R_B}$

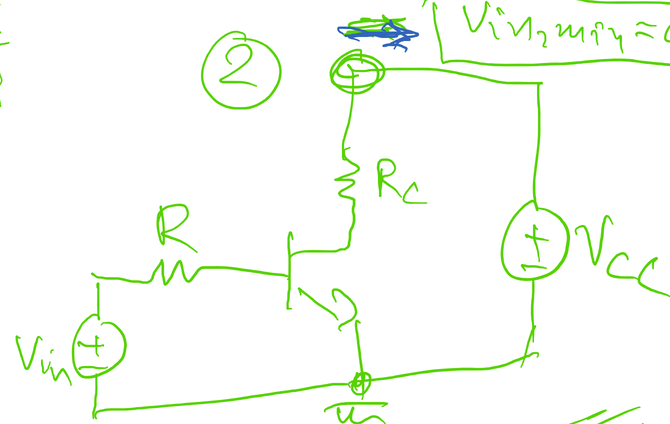
L16Q2: Right-side KVL: Find an equation relating I_{max} to V_{min}.

L16Q3: Left-side KVL: Find the smallest V_{in} such that $I_B > 0$ (if $V_{on} = 0.7\ V$)?

$\boxed{V_{in} \geq V_{on} = 0.7V}$ BJT is on

$\boxed{V_{in,min} = 0.7V}$



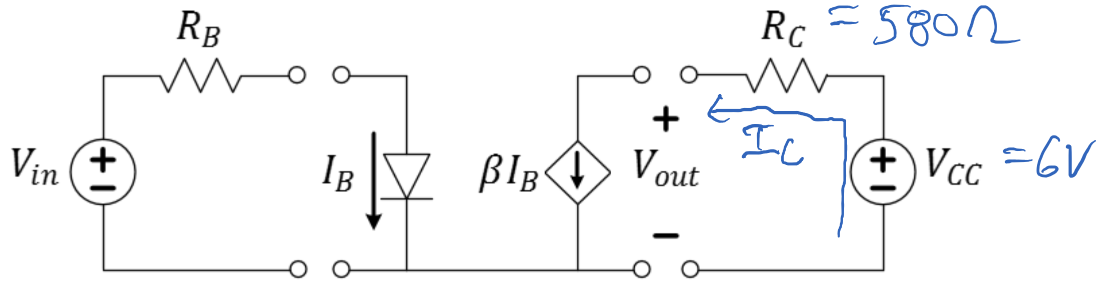


$\frac{V_{CC} - V_{out}}{R_C} = I_C$

$$\boxed{V_{out} = V_{CC} - R_C I_C}$$

→ Q2 $V_{out,min} = V_{CC} - R_C I_{max}$

Two Loops Coupled by Current Equation



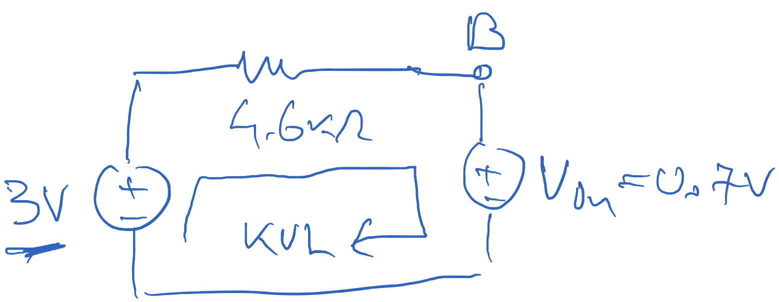
$\beta = 100$
$V_{min} = 0.2V$

Constraints:

- Limited current range: $0 \le \beta I_B \le I_{max}$ (implied by V_{min})
- Limited voltage range: $V_{out} \ge V_{min} \approx 0$

L16Q4: What is I_B if $V_{in} = 3\ V$ and $R_B = 4.6\ k\Omega$? $V_{on} = 0.7V$

L16Q5: Let $V_{CC} = 6\ V, R_C = 580\ \Omega, V_{min} = 0.2\ V, \beta = 100$. What is I_C under the same input settings as the previous question?



Q4. $I_B = \dfrac{3V - 0.7V}{4.6k\Omega} \approx 0.5mA$

Q5. $I_C = \beta \cdot I_B = 100 \cdot 0.5mA$

$I_C = 50mA$

$V_{out} = V_{CC} - R_C \cdot I_C = 6V - (580\Omega) \cdot (50mA) = 0.5V$