Lecture 2

01/23/23

Electric Charge

- Measured in coulombs
- Q or q is the typical variable for charge

Charge of an electron:

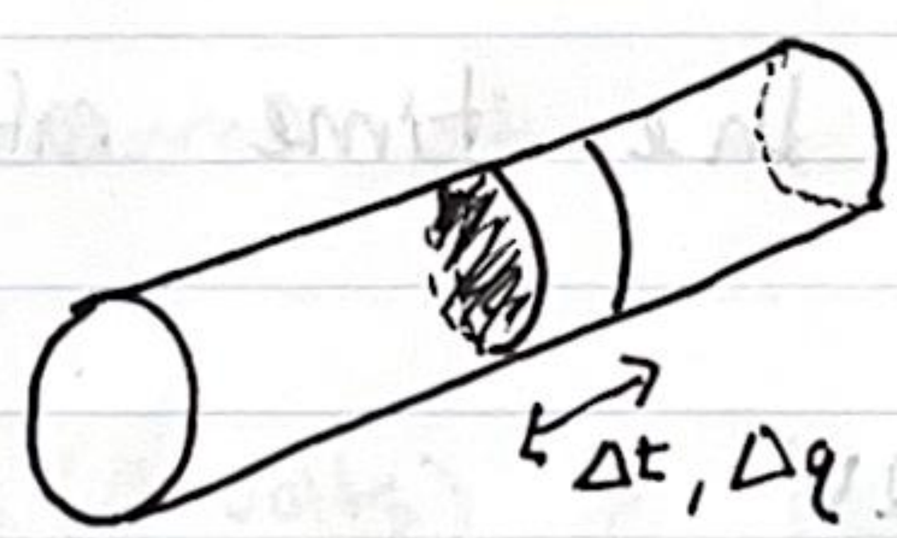
$$\boxed{-1.6 \times 10^{-19}\ C}$$

Electric Current

- Rate of flow of an electric charge
- Measured in Amperes "amps" A
- I or i is used as the variable for current

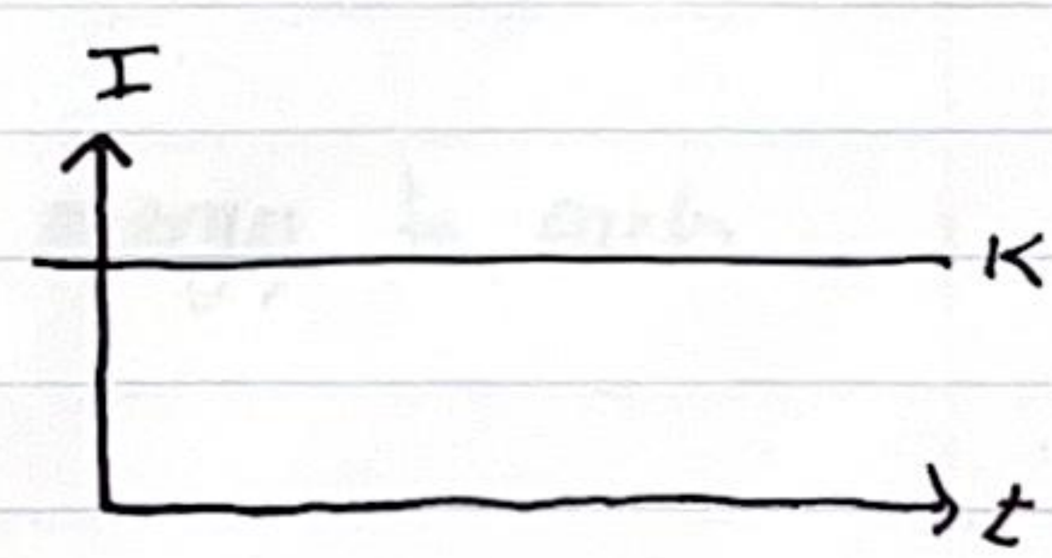
$$i(t) = \frac{dq(t)}{dt}$$

- $1A = 1\ C/s$



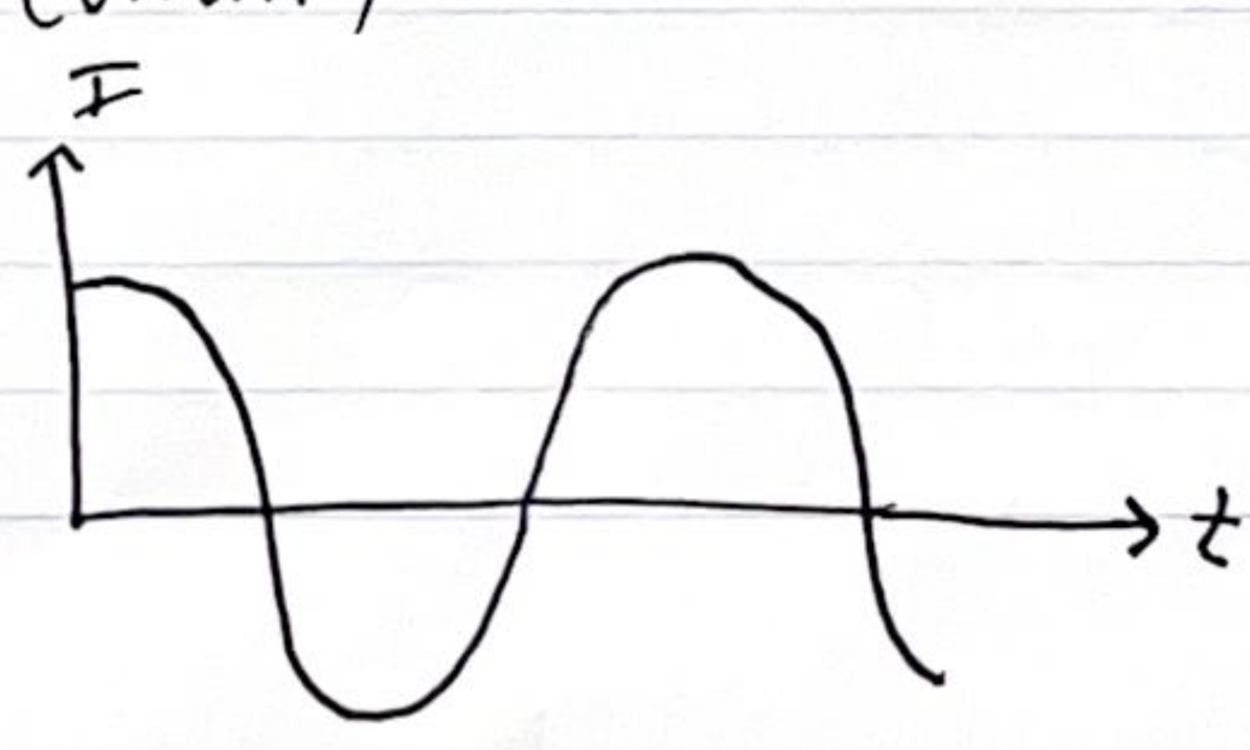
DC Current (Direct Current)

$$I = \frac{\Delta Q}{\Delta t} = K\text{, a constant}$$



AC Current (Alternating Current)

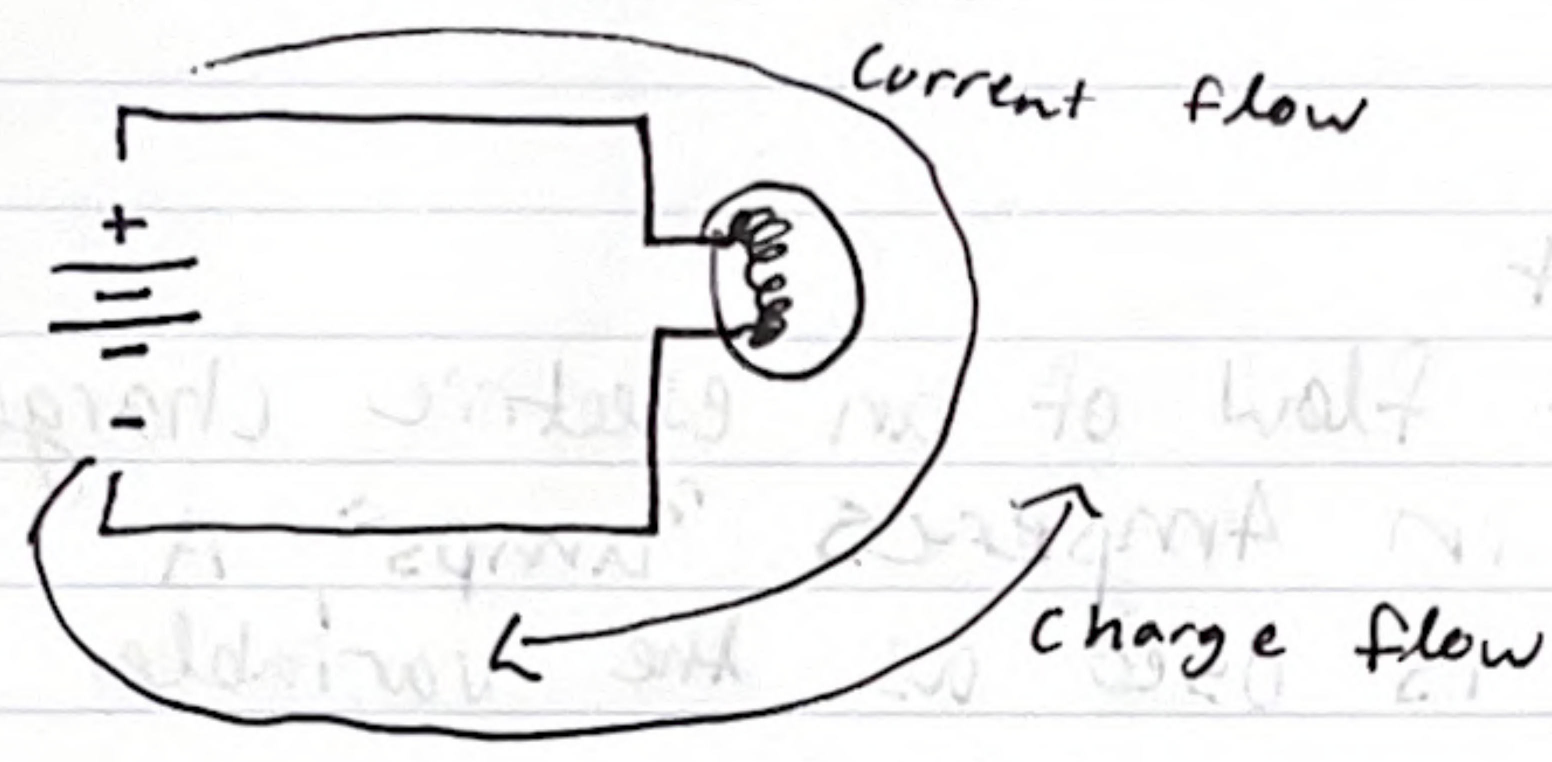
$$i(t) = A\cos(\omega t)$$



If the electrons are moving left to right in the wire, what direction is the electrical charge
- left to right

Voltage

$$\Delta V = \frac{\Delta E}{\Delta Q}$$



Power is the time rate of energy transfer

$$E = QV$$

Lecture 3

Jan 25, 2023

Parallel: Two branches in parallel are connected such that the current in the adjacent branch must split/combine. If

Measoring and Modeling Circuits

- Ammeter
- Voltmeter
- Current-Voltage (IV) plots
  - Ohm's law
  - Cylindrical Conducters/Resistors
  - IV for linear circuit models

- Voltage cannot be measured at one point - it is differential

- It would take no energy (0 volts) to move charge in an ideal conductor

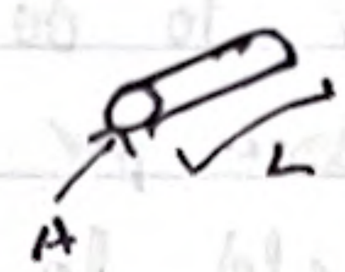
- A 9V battery delivers 9 Joules of energy to each Coulomb of charge it moves

$$[V] = \frac{J}{C}$$

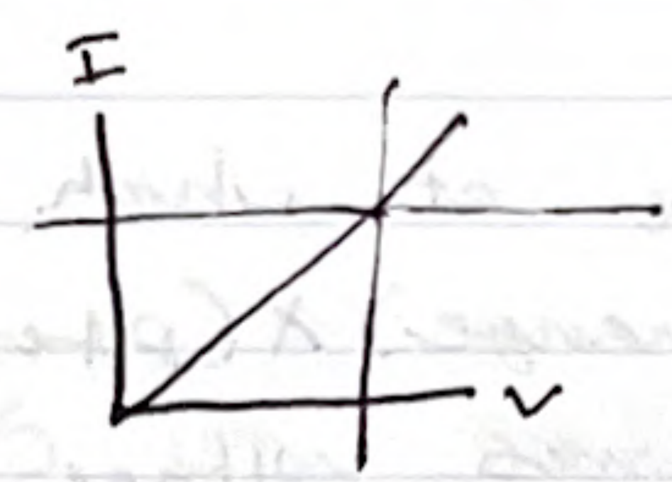
Lecture 5

Resistance of a conductor

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

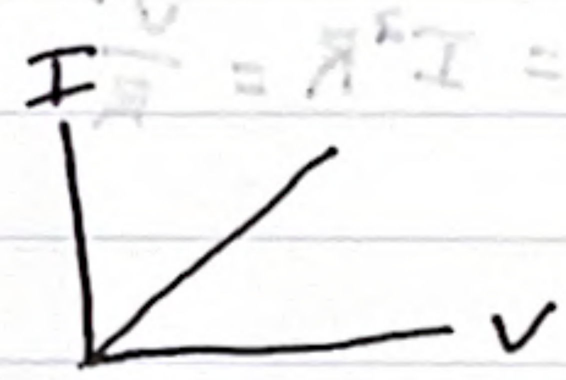


IV Characteristics $\quad I = mV + b$



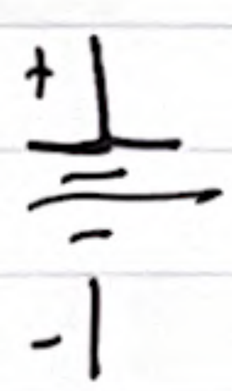
Ohms law

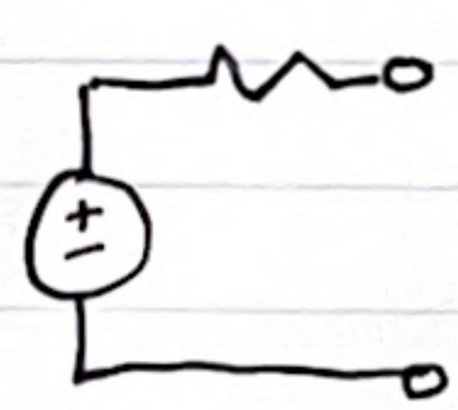
$$I = \frac{V}{R}$$



Modelling

battery →





Thevian Circuit

Voltage + Energy

- Energy is the ability to do work/heat measured in Joules
- Voltage is the work done per unit charge (J/C) against a static electric field to move charge between two points

$$V = \frac{\Delta E}{\Delta Q}$$

Power is the rate at which energy is transfered
- (rate of change) x (potential difference)
- current times voltage

$$P = \frac{\Delta E}{\Delta t} = \frac{\Delta Q}{\Delta t} V = I^2 R = \frac{V^2}{R}$$ (Power is non-negative)

$$E_{input} = E_{used} + E_{wasted}$$

Electrical Energy Storage:

- Battery
- Capacitor

Efficiency

$$Energy_{input} = E_{useful} + E_{waste} = \eta(E_{input}) + (1-\eta)E_{input}$$

η (Eta) = Efficiency

Lecture 6

$P = \frac{\Delta E}{\Delta T} = \frac{\Delta Q}{\Delta t} V = IV$ $\quad V = \frac{\Delta E}{\Delta Q}$

$P = I^2 R = \frac{V^2}{R}$

$C = \frac{Q}{V}$

↑ capacitance

C, the capacitance, is the charge-to-voltage ratio of a capacitor

$E_{capacitor} = \frac{1}{2} C V^2$ $\quad E = \frac{Q^2}{2C} = 9$

$E_{Battery} = E_{cap} + E_{waste}$

$\Delta E_{waste} \geq \frac{1}{2} C V^2$

$Q = It$

Lecture 8

Resistor

$$P = IV = \frac{V^2}{R} = I^2 R \geq 0$$

$$I^2_{max} = \frac{P_{max}}{R} ; \quad V^2_{max} = P_{max} R$$

Capacitor

$$C = \frac{Q}{V} \qquad E_{capacitor} = \frac{1}{2} C V^2 = \frac{1}{2} Q V = \frac{Q^2}{2C}$$

Battery

$$E_{battery} = CV^2 = QV$$

(?)

$$C = \frac{Pt}{V}$$

$$[Q] = Ah$$

Kirchhoff's Current Law (KCL) - Conservation of Charge
Kirchhoff's Voltage Law (KVL) - Conservation of Energy

Node: point where two or more elements are connected

Branch: A two-terminal circuit element

Loop: A closed path in a circuit where two nodes are not traversed twice

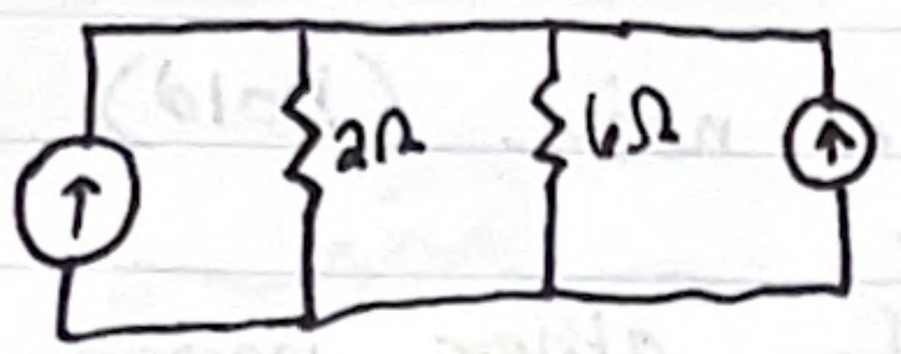
Lecture 9

Voltage divide rule:

$$\frac{R_1}{R_{tot}}(V_s) = V_1$$

Current divider rule:

$$I_K = \frac{R_{eq}}{R_K} I$$



Superposition Theorem

• The total current in any part of a linear circuit equals the algebraic sum of the currents produced by each source seperately. To evaluate the seperate currents to be combined, replace all other voltage sources by short circuits and all other current sources by open circuits

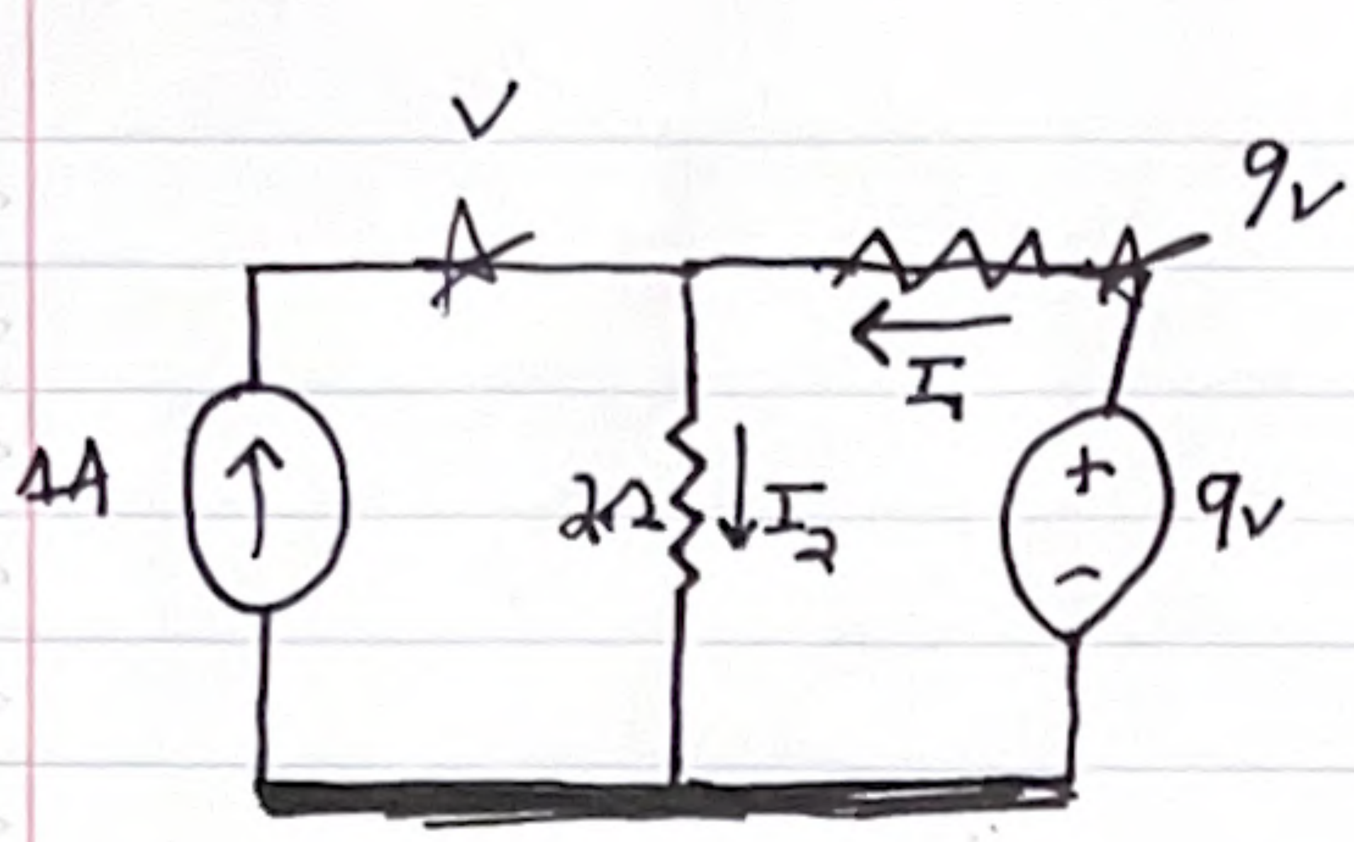
The Node Method

1. Identify or pick "ground" (0v ref)

2.

3.

4.



1. select a node (bold)
2. identify other nodes (A)
3. assign voltages

KCL: $I + I_1 = I_2$

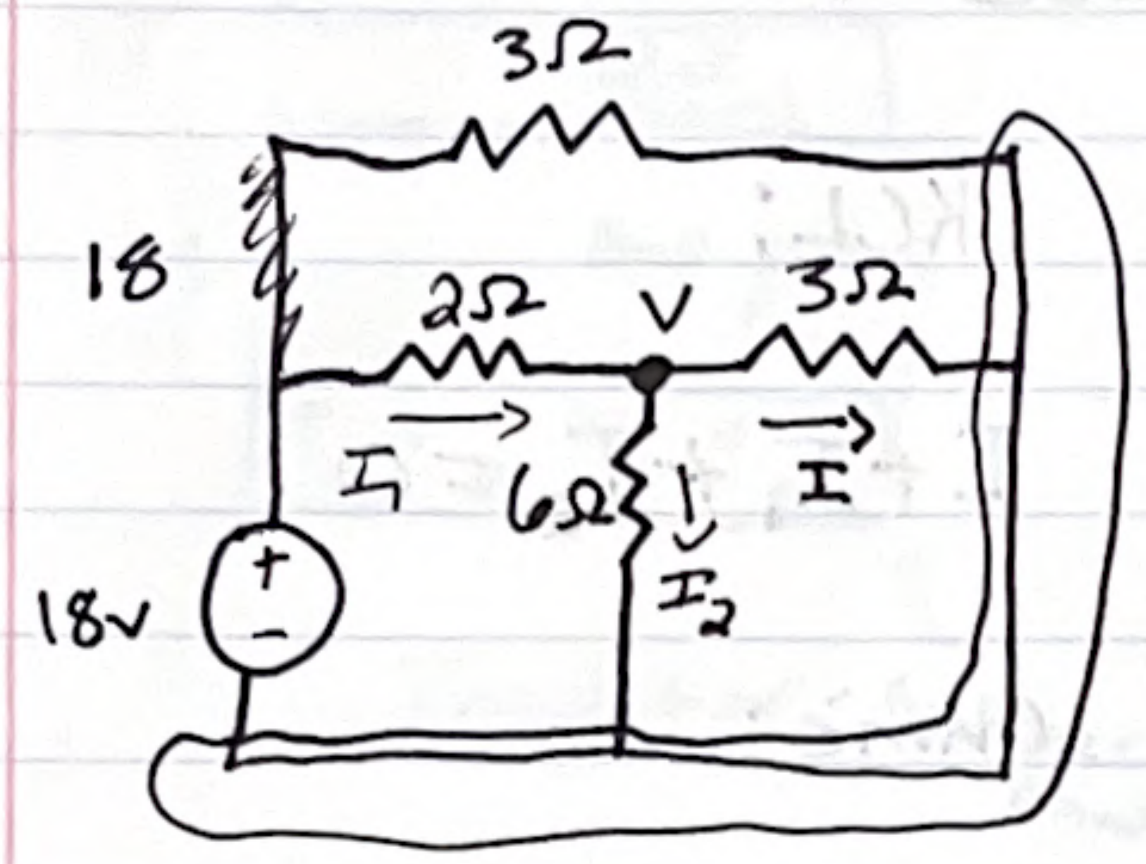
$1A + I_1 = I_2$

Ohm's: $1 + \frac{9-v}{6} = \frac{v-0}{2}$

$9 - v + 6 = 3v$

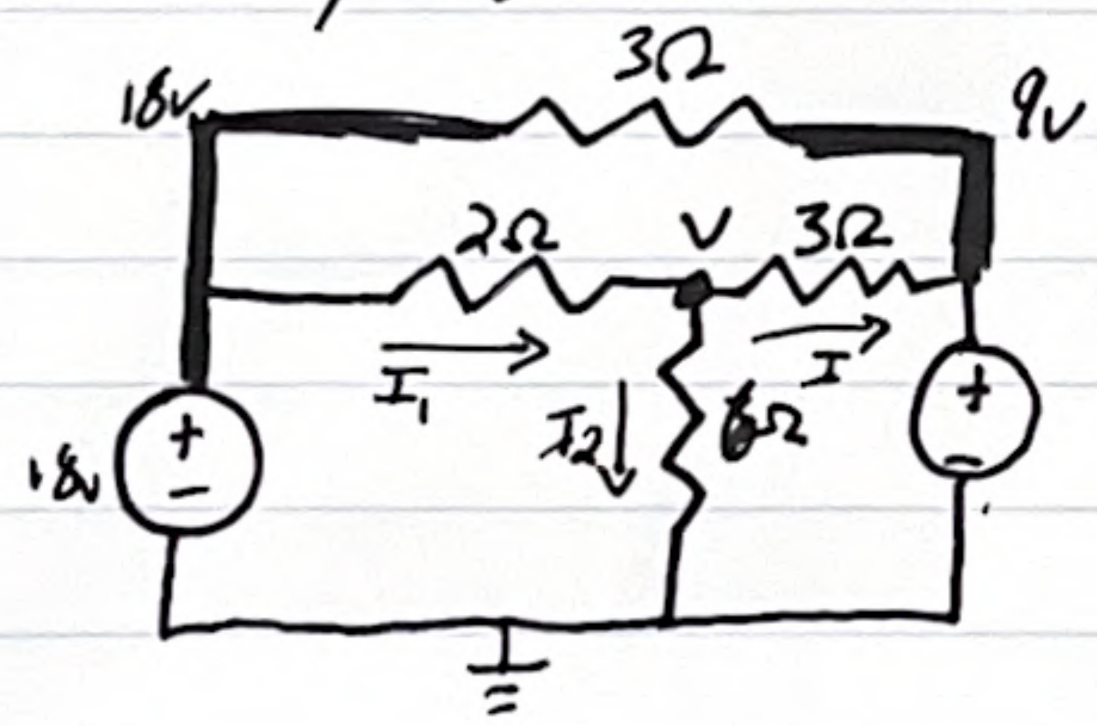
$V = \frac{15}{4} v$

Another example



1. Identify ground node
2. Other nodes
3. assign voltages

Similar, but with another voltage source



KCL: $I_1 = I_2 + I$

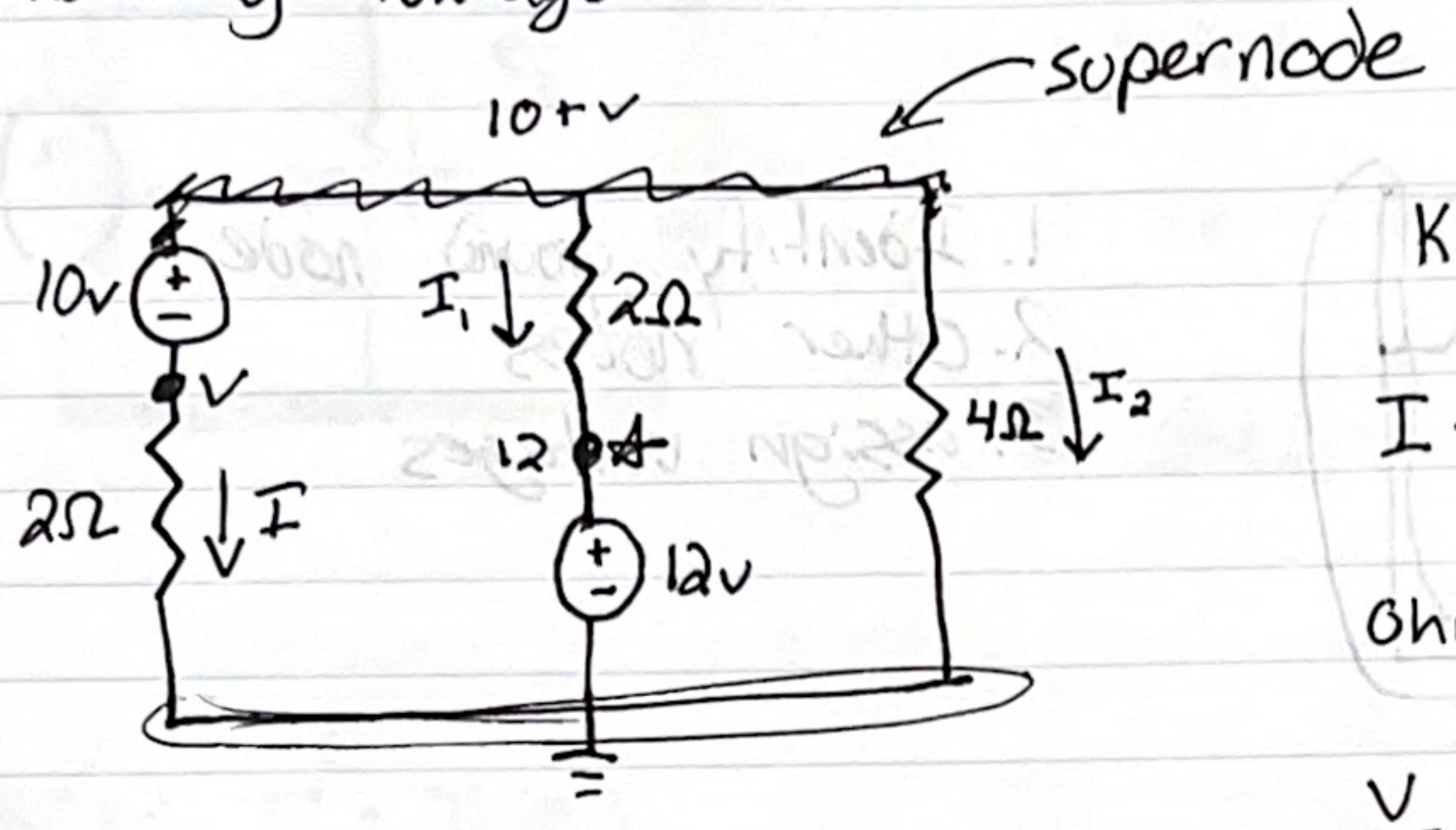
$$\frac{18-V}{2} = \frac{V-9}{3} + \frac{V}{6}$$

$V = 12v$

$$I = \frac{V-9}{3}$$

$I = 1A$

Floating Voltage Source



KCL:

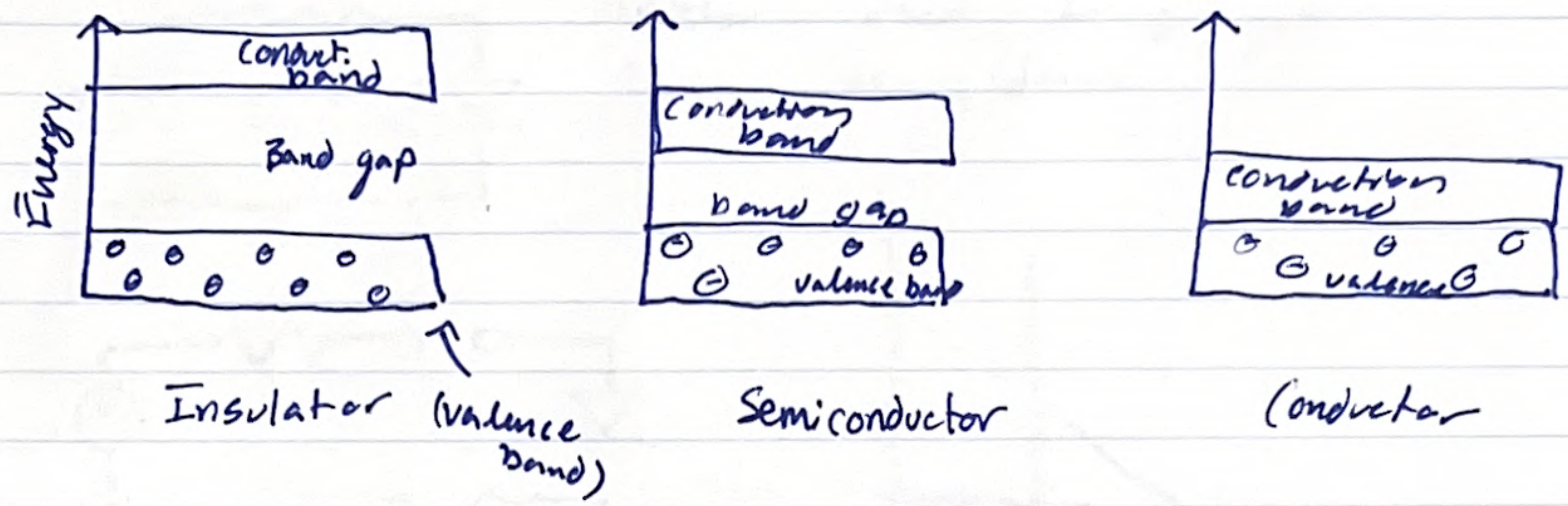
$I + I_1 + I_2 = 0$

Ohm's:

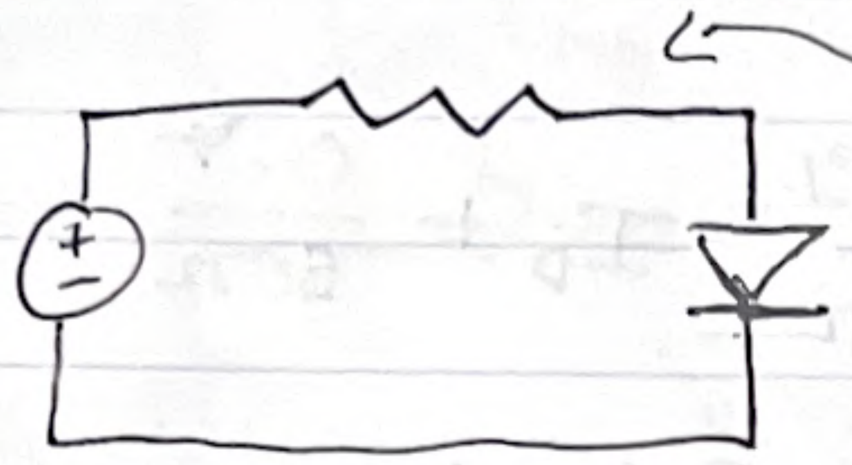
$\frac{V}{2} + \frac{10 + V - 12}{2\Omega}$

Lecture 16

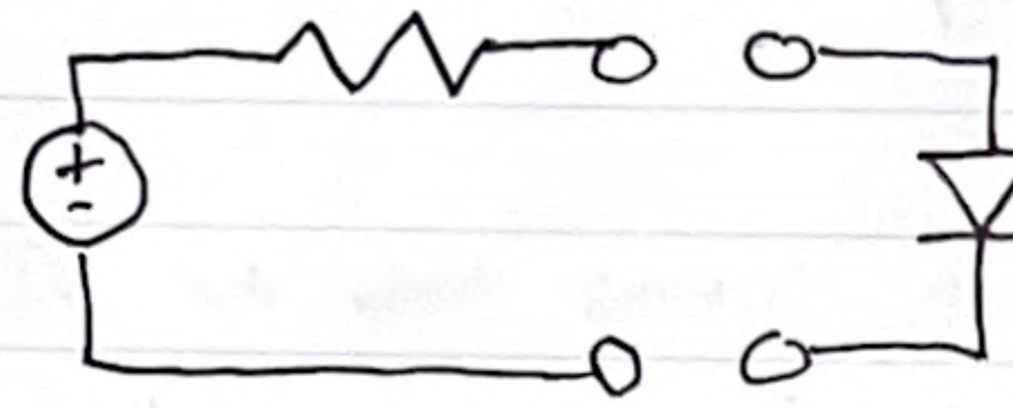
Intro to Diodes

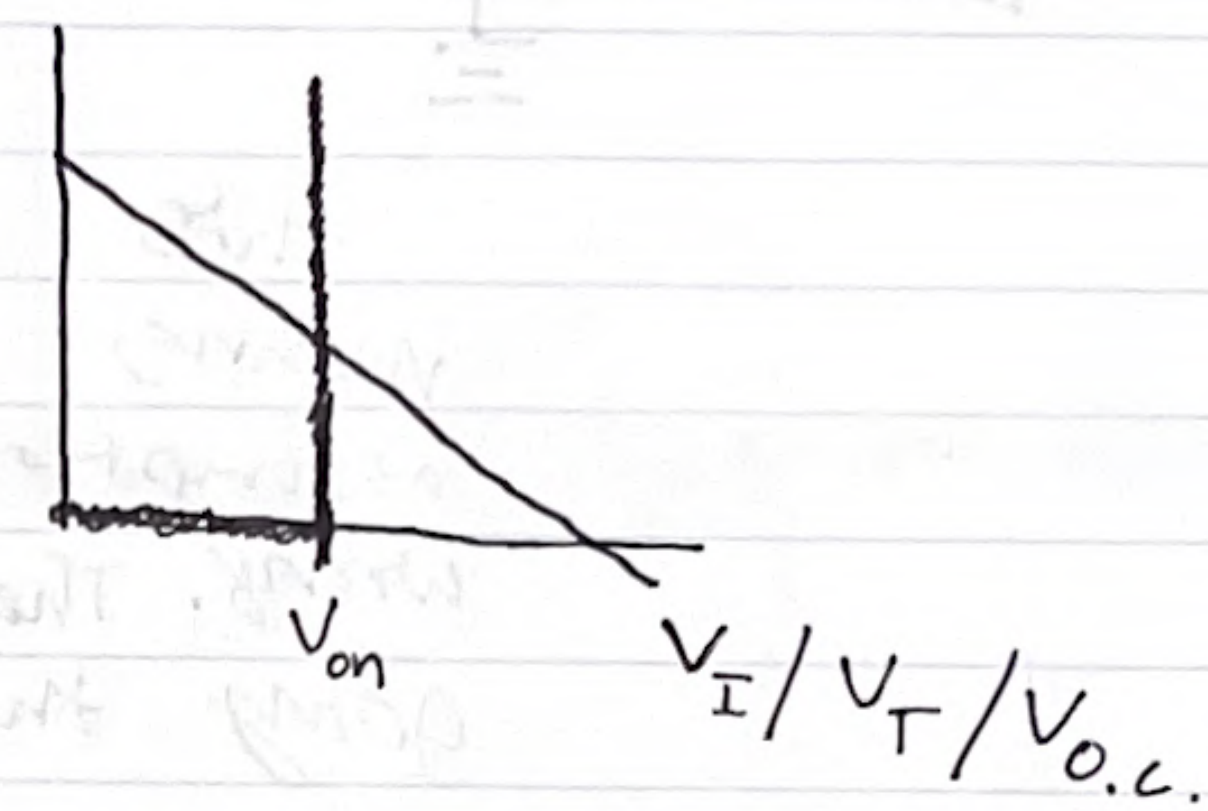


Lecture 17



resistor used to prevent frying the diode

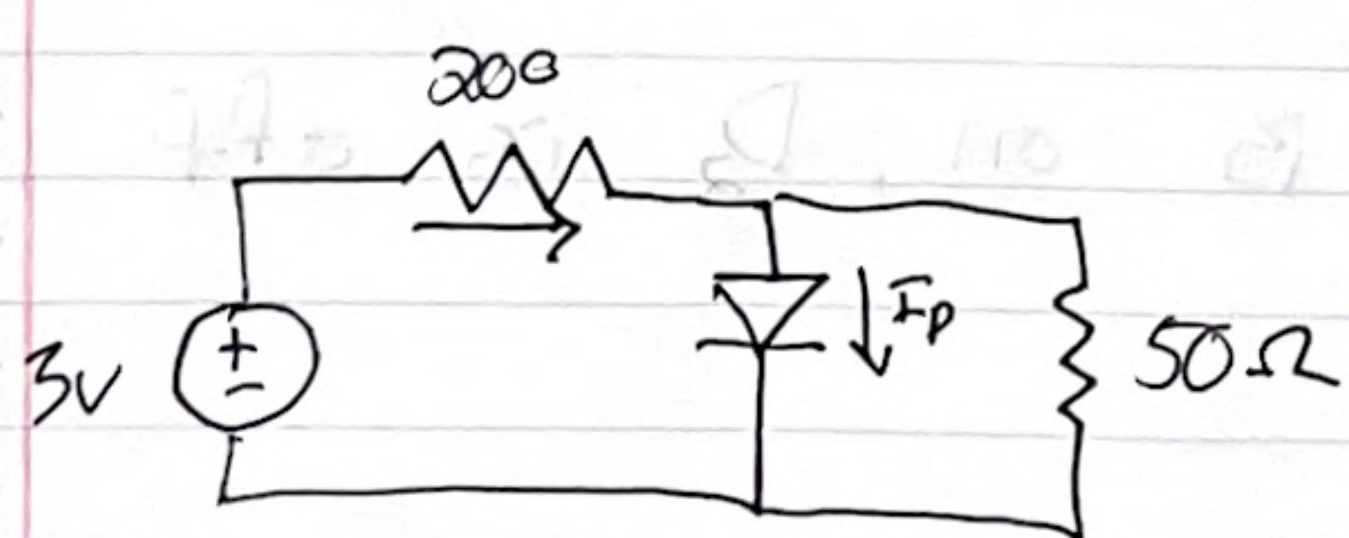




Voltage accross some diodes remain const:

Ex:

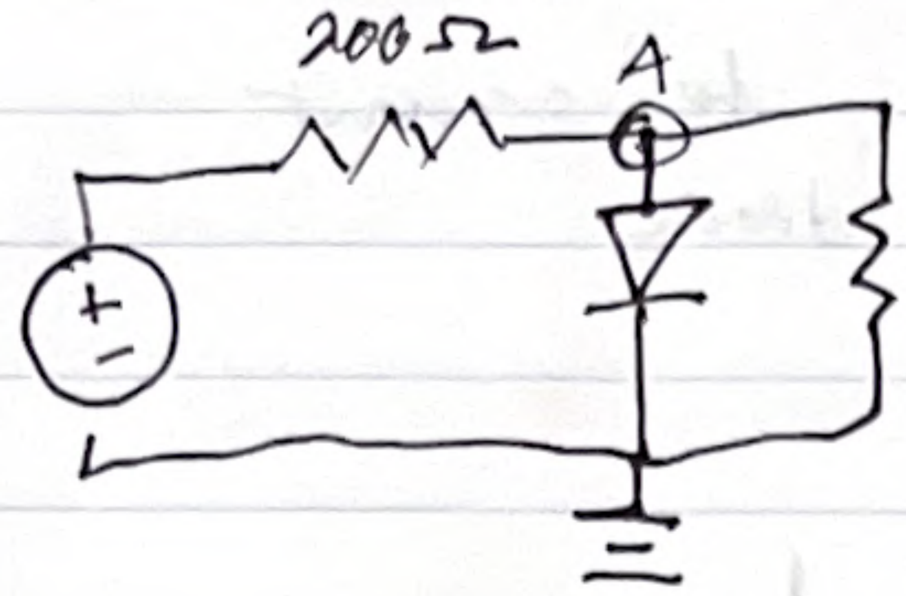
Germanium
Red
Blue



$V_{on} = 0.7$

What is the current through diode?

Use node method

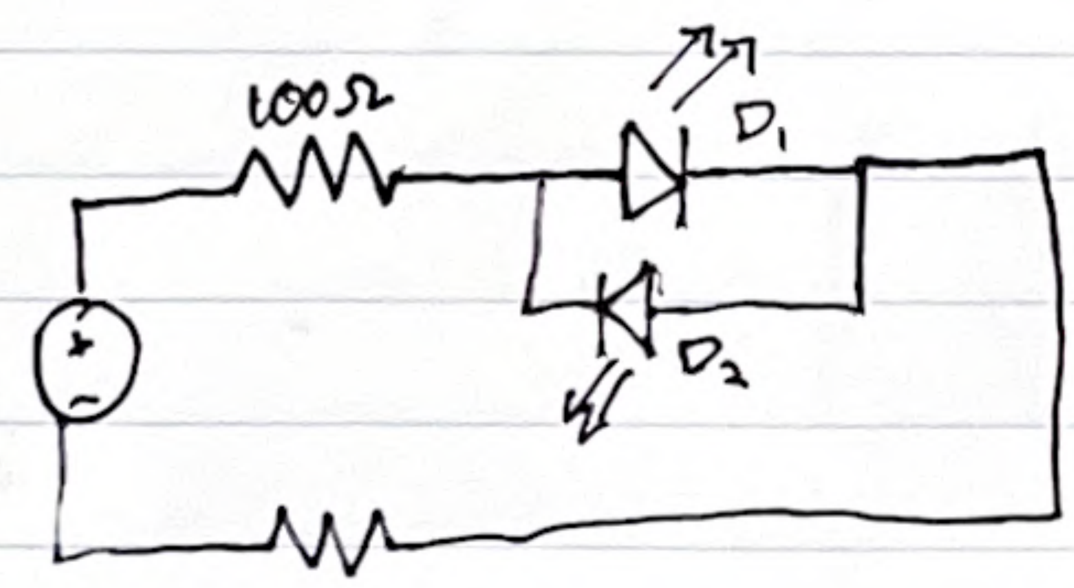


A) $\frac{3_V - 0.7_V}{200\Omega} = I_D + \frac{0.7}{50\Omega}$

$= -2.5mA$

this means our assumption was wrong. There cannot be any current going through the diode!

0mA



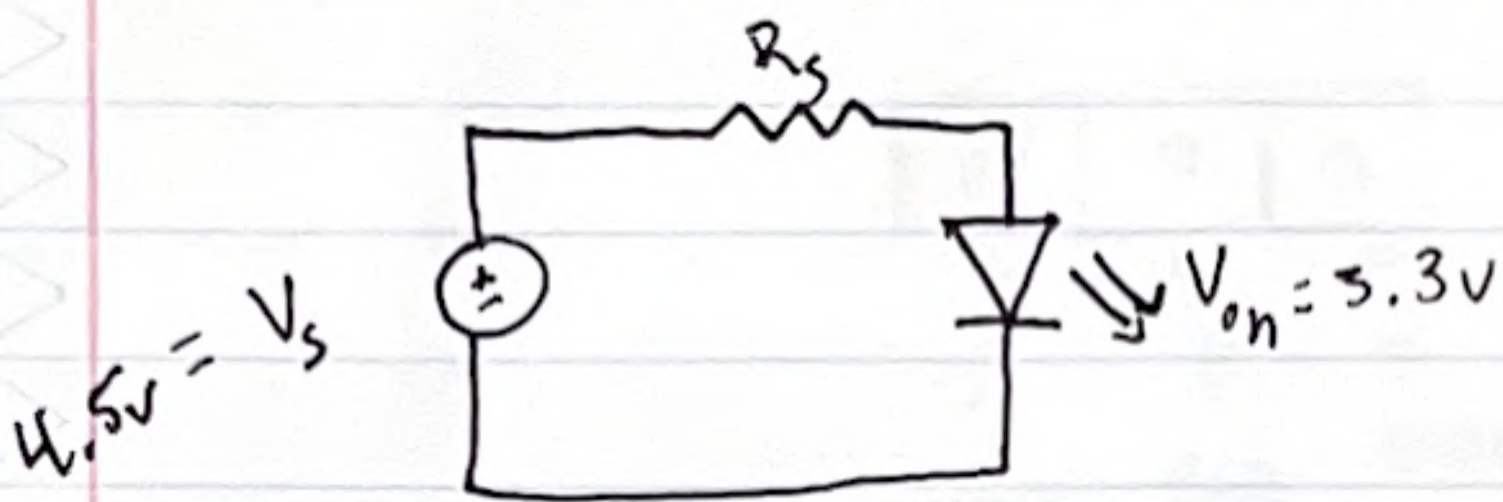
Make assumptions with diode!

Guess and check!

In this case D_1 is on, D_2 is off

Lecture

Current limiting resistors for LEDs



4/5/.016

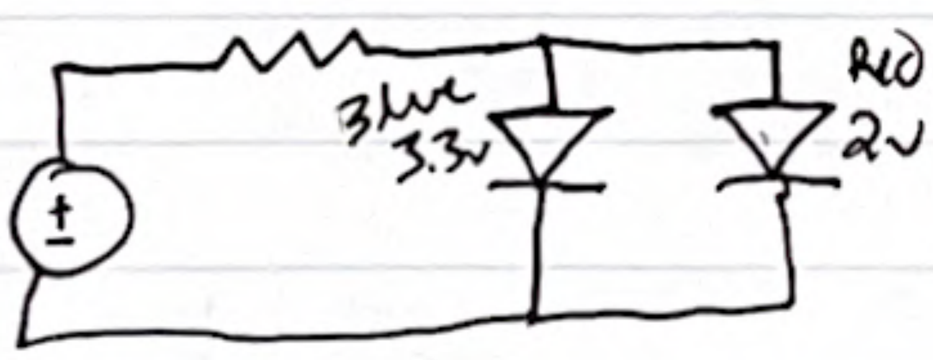
If we want current through the diode to be 16mA, what must R be

$$4.5v - I_c R_s - 3.3v = 0$$

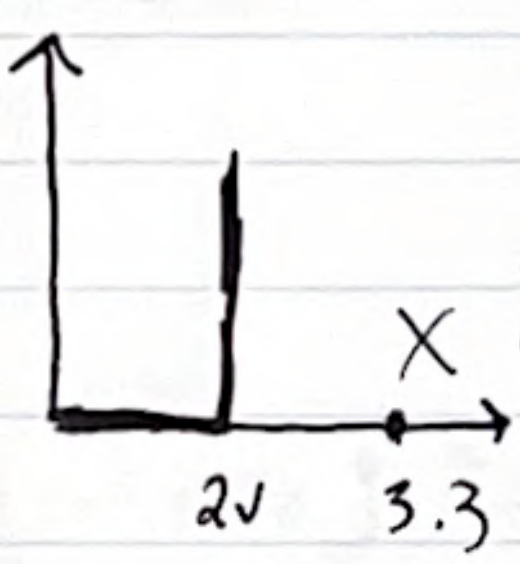
$$4.5 - .016(R_s) - 3.3v = 0$$

$$1.2 = .016(R_s)$$

$$\frac{1.2v}{.016A} = 75\Omega$$



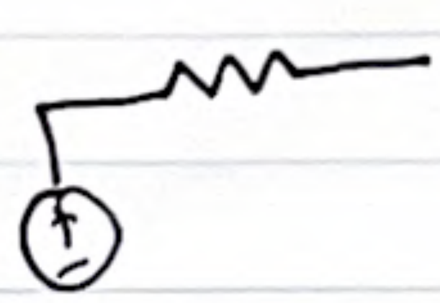
Which LED's will be on?
just RED!



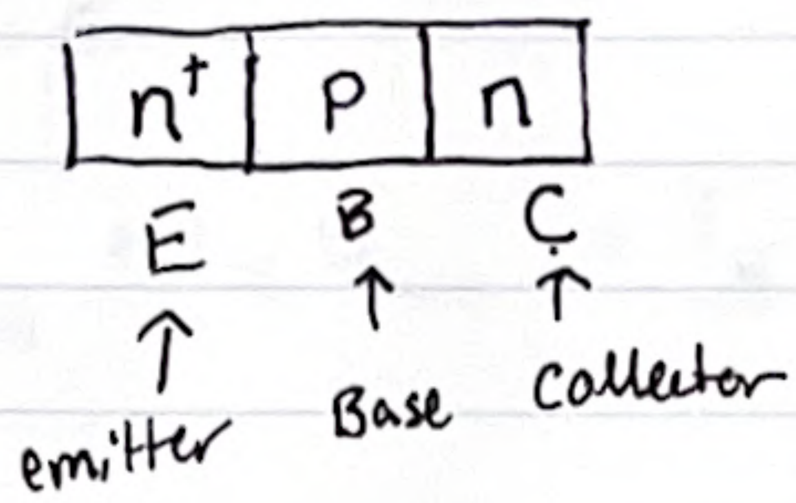
100

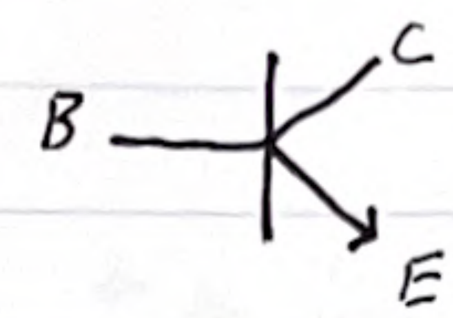
$.1 = 2(I)$

$I = .05$

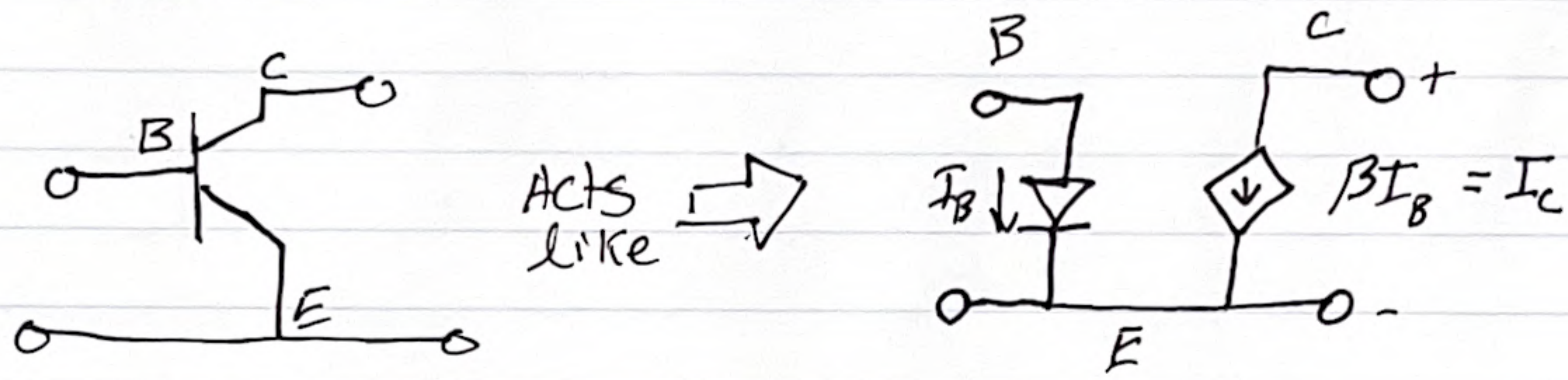


IV Characteristic of a 3-terminal device





NPN model:



Power is consumed

Constraints:

- $I_B \geq 0$ and $\beta > 0 \Rightarrow \beta I_B \geq 0$
- $V_{out} \geq V_{min} \geq 0 \Rightarrow I_c \leq I_{max}$

$$I_c = \min\{\beta I_B, I_{max}\} \geq 0$$

Lecture 20

$$P_{BJT} = P_{BE} + P_{CE}$$

$$= I_B V_{BE,on} + I_C V_{out} = I_B V_{BE,on} + I_C V_{CE} \geq 0$$

Lecture 21

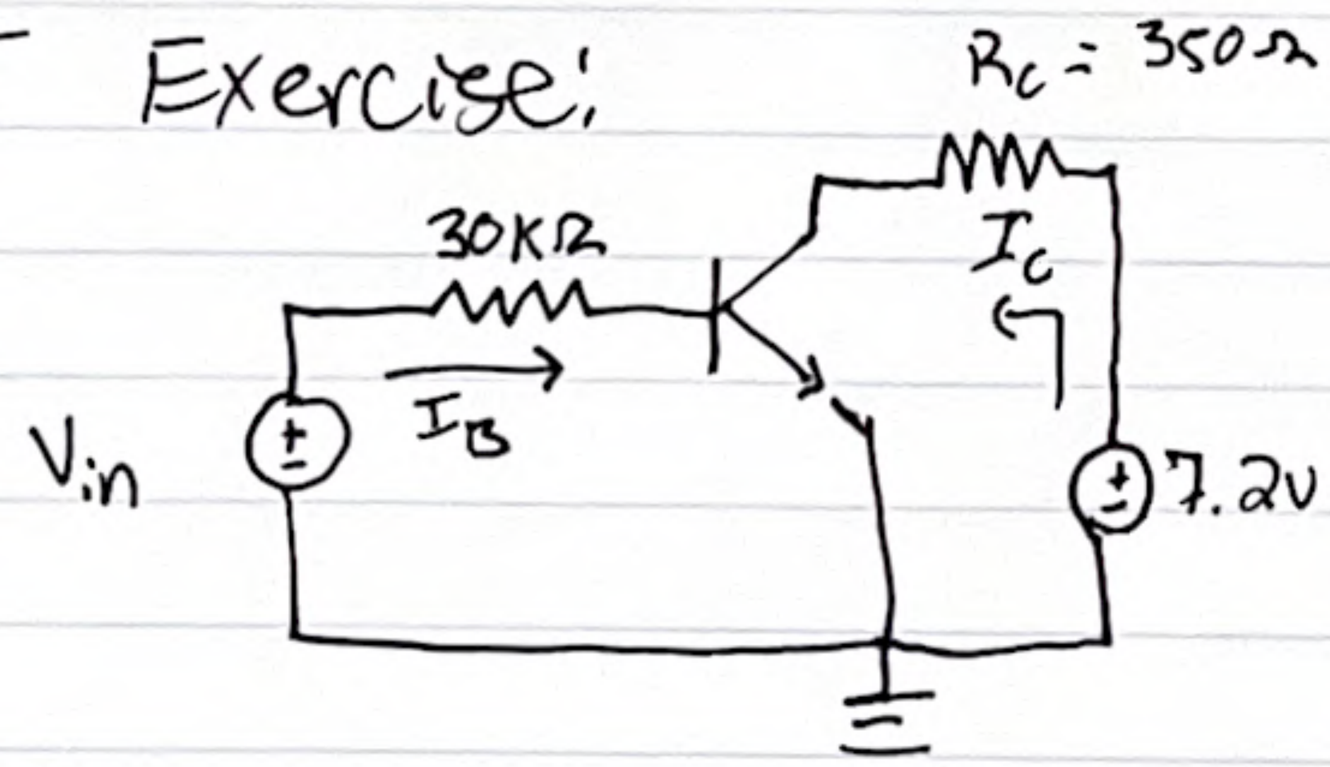
Recap:

$$0 \leq I_C = \min \begin{cases} \beta I_B = \beta^{V_{in} - V_{BE,on}} \\ I_{C,sat} = \dfrac{V_{CC} - V_{CE,sat}}{R_C} \end{cases}$$

↑
collector current

$$V_{out} = V_{CE} = V_{CC} - I_C R_C$$

BJT Exercise:



$\beta = 100$

$V_{BE,on} = 0.7v$

$V_{CE,sat} = 0.2$

What V_{in} would ~~cause~~ drive the trans. to the edge of saturation

I_C

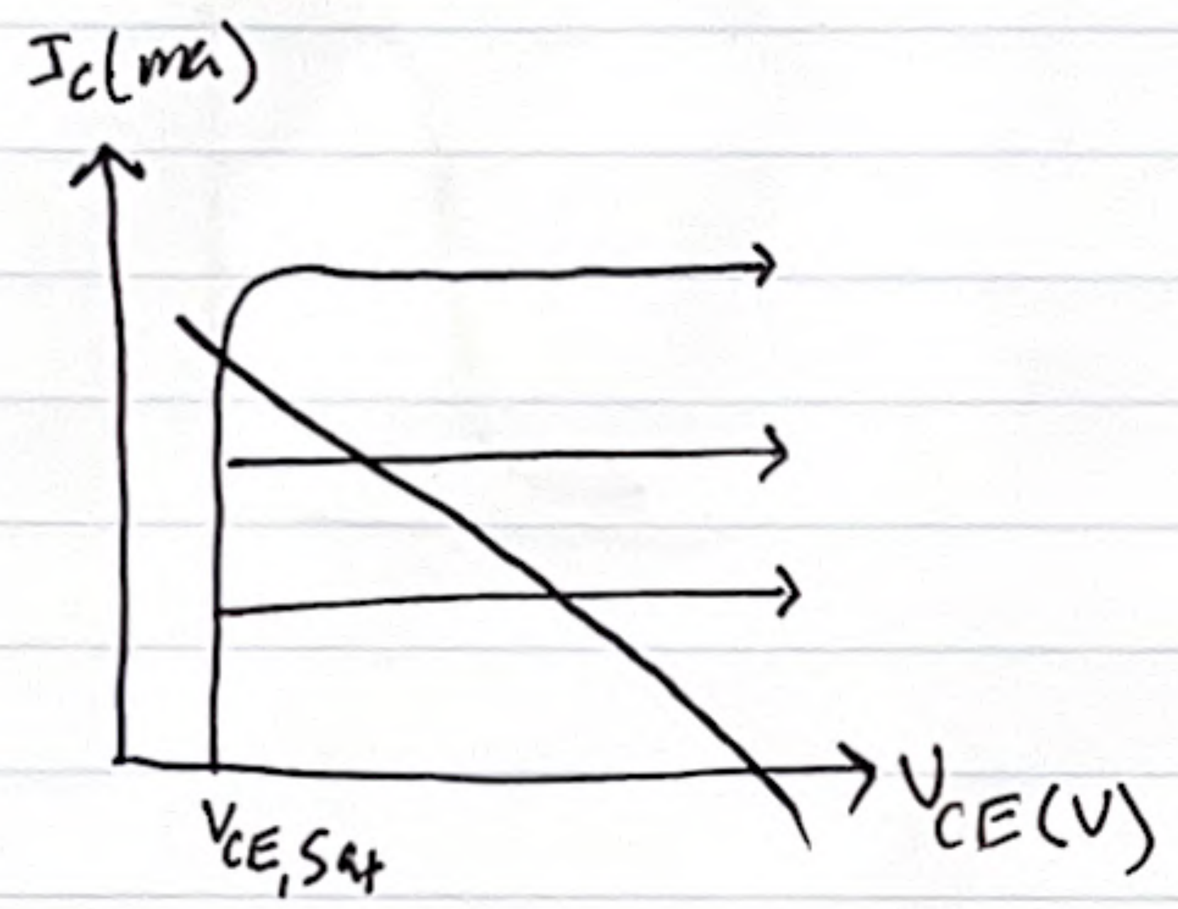
$$\beta I_B = I_{C,sat}$$

$$100\left(\frac{V_{in@sat} - 0.7v}{30000\,\Omega}\right) = \frac{7.2 - 0.2v}{350}$$

$$V_{in@sat} = 6.7v$$

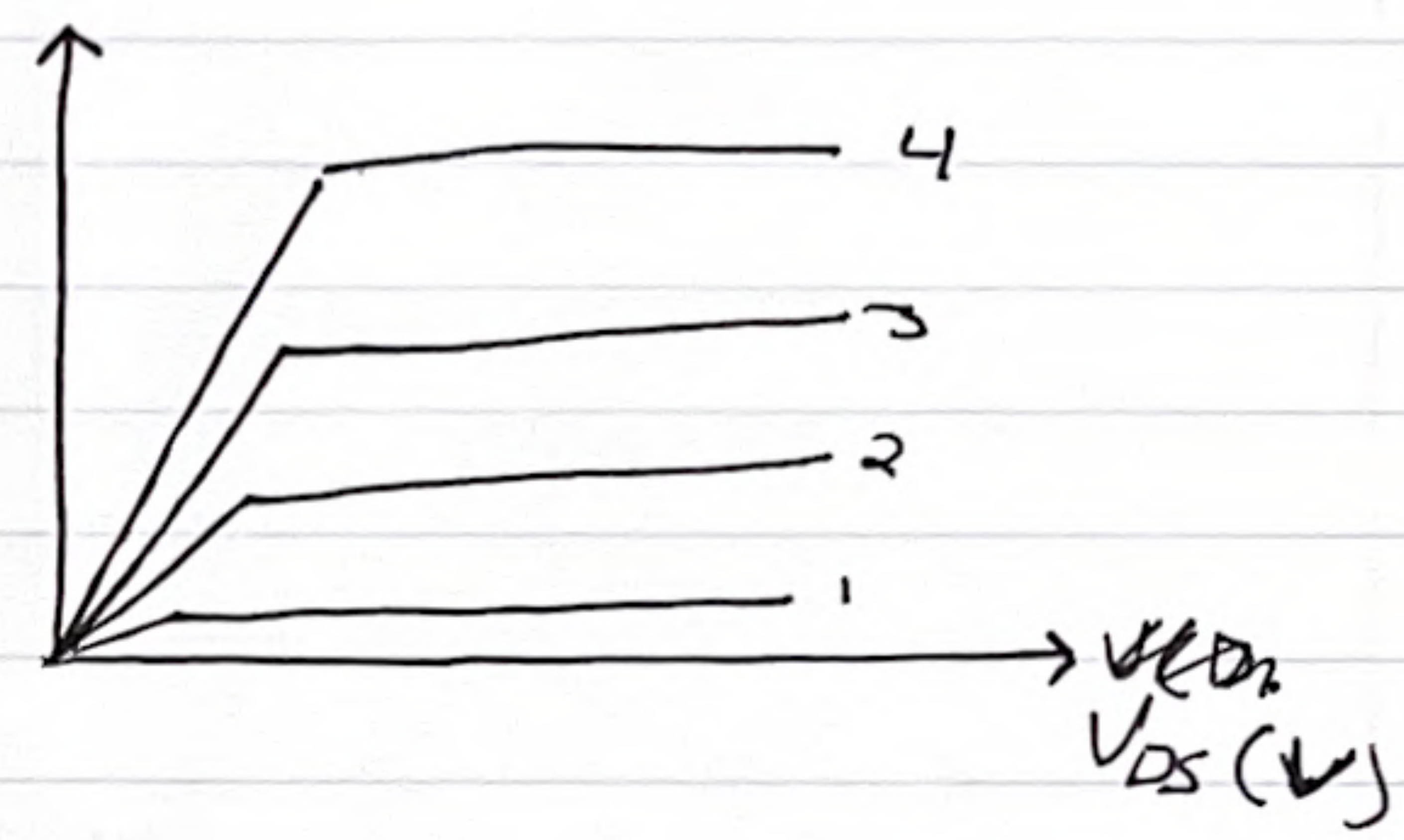
BJT

$V_{out} = V_{CE} = V_{CC} - I_C R_C$



Mosfet

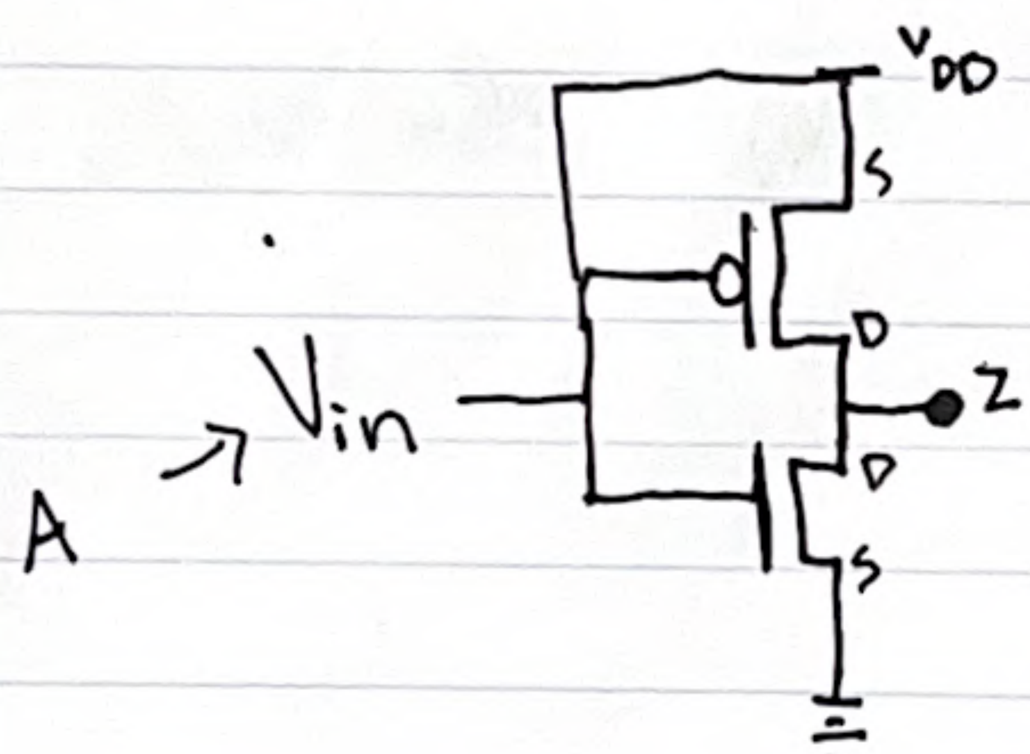
$V_{out} = V_{DS} = V_{DD} - I_D R_D$



Lecture

nMos

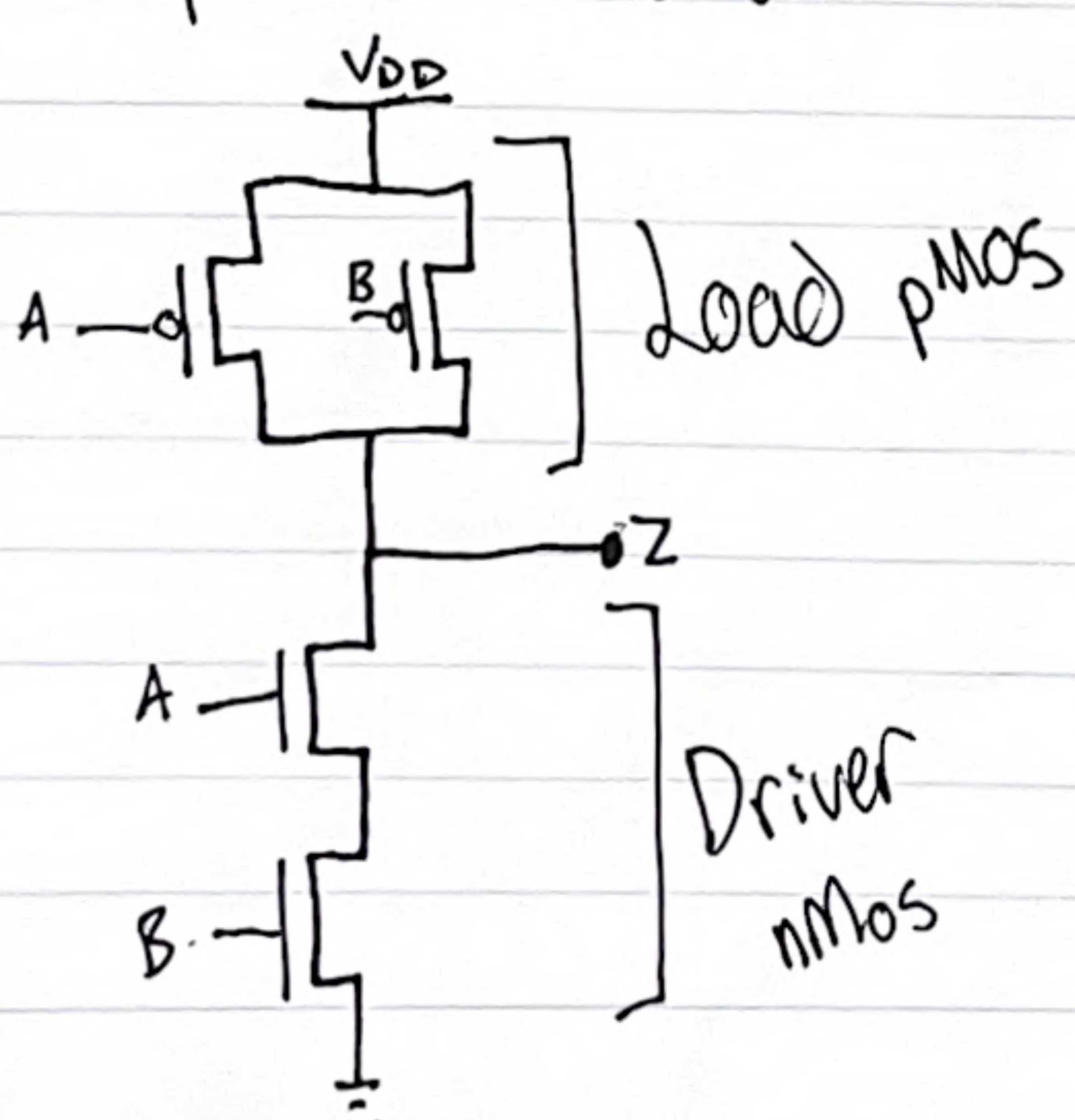
CMOS implementation of inverter



input(A)	output(Z)
0	1
1	0

When Vin high: nMos ON
pMos OFF

Two Input CMOS Circuit



A	B	Z
0	0	1
0	1	
1	0	1
1	1	0

Lecture

CMOS Logic Pt II

Power consumed by a switching FET:

$$P = \alpha f C V^2 n$$

where:

- α - activity factor
- f - switching frequency
- C - load capacitance
- V - switching voltages
- n - number of transistors switching

Photodiodes and Solar Panels