Unit 1

Textbook: Appendix A, Ch. 1-4

Basics:

- Electrical Quantities (Definitions, Units, Unit Derivations)
- Passive Sign Convention
- Power Delivery
- The Basic Circuit
- Kirchoff's Laws

Equivalent Circuits:

- Fundamental Combinations
- Equivalent Resistances
- Voltage / Current Dividers
- Source Transformations
- Thevenin & Norton

Analysis Methods:

- Node Voltage
- Mesh Current
- Superposition

Unit 1, Section 1: Basics!

Base Assumptions and Electrical Quantities:

There are some basic units and definitions that are vital to everything else, if only so that we can get a bit of intuition as to whats happening and what's being described when hearing a word.

The biggest assumption we make in this class is that all components are lumped and ideal

Lumped - There is no "unit length", everything happens as if it were a point. There's no resistance over a length, it's just resistance

Ideal - Everything behaves theoretically, there's no difference between calculated and actual values

Base SI Units!

(Not much to add, just learn table, will go into detail on a few)

Quantity	Basic Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	degree kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Current! The net change in charge through a 2-D surface over time

Measured in Ampere's (A) $= \frac{\text{coulomb}}{\text{sec}}$ (C/s) $= \frac{dq}{dt}$

Charge: The amount of force something experiences when placed in an electric field

Measured in Coulombs (C) = $6.24 \times 10^{18}\ e^-$

$1\ e^- = 1.6 \times 10^{-19}$ C

We assume that charge is in discreet quantities of the electron, it can be positive or negative, and cannot be created or destroyed

Energy - The capacity to do... something (Work)

Measured in Joules (J) : $N m$ = Force · Distance

By Conservation of energy, it cannot be created or destroyed

Voltage - The electric potential energy per unit charge (Electric Potential)

Measured in Volts (V) = J/C

Power - The actual doing of work and using of energy per unit time

Measured in Watts (W) = J/s

Most common use is $V \cdot I$: $\left(\frac{J}{C}\right)\left(\frac{C}{s}\right) = J/s$

Resistance - The measure of opposition to current flow

Measured in Ohms (Ω) = V/A

Inverse is Conductance, measured in Siemens (S) = A/V

Creates a strict ratio known as ohms law that most things in this class follow

Frequency - How often, of "frequent" something happens

Measured in Hz = 1/s (cycles per second)

Measured in rad/sec (angular frequency)

Often use angular frequency b/c we deal w/ sinusoidal waves in AC

$\omega = 2\pi f$

Derived SI units:

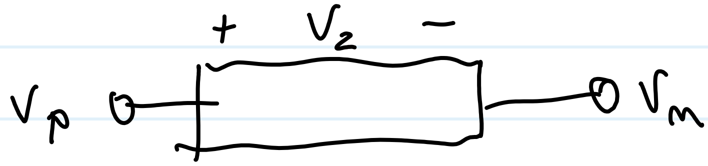
Quantity	Unit Name (Symbol)	Formula
Frequency	hertz (Hz)	s^{-1}
Force	newton (N)	$kg \cdot m/s^2$
Energy or work	joule (J)	$N \cdot m$
Power	watt (W)	J/s
Electric charge	coulomb (C)	$A \cdot s$
Electric potential	volt (V)	J/C
Electric resistance	ohm (Ω)	V/A
Electric conductance	siemens (S)	A/V
Electric capacitance	farad (F)	C/V
Magnetic flux	weber (Wb)	$V \cdot s$
Inductance	henry (H)	Wb/A

Passive Sign Convention (PSC):

A vital concept for this course is the passive sign convention, as it sets consistency and determines the signs of our calculations for everything. It is independent of components, and you will cry if you get it backwards, so don't. It will cause pain.

Key Rule: A positive current direction is one that heads in the direction of a voltage <u>drop</u>

So a drop is positive, but what does that mean? Lets start with just a plain component



Those little plus and minus signs on it are describing the potential relative to the <u>component</u>. The plus sign is the side of the device w/ a higher potential, and the minus sign is the side with the lower potential, if we're following the PSC

In our diagram, following the convention, you might have 3.3V, 5V, 9V, 12V or any other voltage on the positive side, and then 0.5, 1V, 2V, or 0V on the other, the actual values really don't matter, it's just that the voltage of the component is $V_2 = V_p - V_m$,
from this formula can you see why a voltage drop is positive for PSC? If it wasn't, we'd say that voltage rises were positive, which would leave a whole lot of negative signs since almost nothing (other than sources) produce a voltage rise.

So.., we know when a voltage is postive under the PSC, and thats when higher potential is on the + side. But calculations almost never happen with just voltage, so we need to think about current too.

Getting the sign right for current isn't terrible, but you have to think about what current is. If you imagine electric current like a river, where water is flowing, then this gets a bit easier.

Water, has some amount of potential energy pretty much all the time. If you put it at the top of a ramp, it will naturally flow down, almost as if we could assign a positive sign to that drop in potential to say "Yay! you obeyed the laws of physics! Good Job!". Do you see where I'm building to?

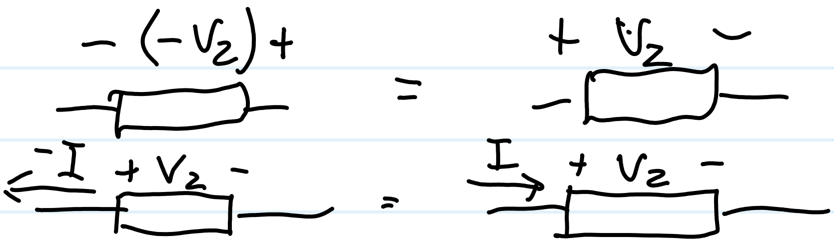
Electric current, is the same way, if it's positive it's flowing from a high to a low potential, just like how water moves. If it decides it wants to flow from low to high, something funny is going on so we give it negative sign, because it would be pretty weird if water just started flowing uphill.

So in summary!

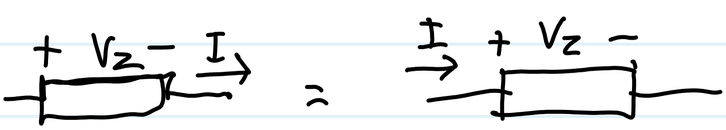
Voltage is positive if the higher potential is on the positive side

Current is positive if it flows towards a voltage drop (the positive terminal of a component)

Quick note:



Don't be tricked by a negative. Negatives mean reversed direction/Polarity



Also... you can shift your current symbol as long as you keep direction the same

Power Delivery!

Armed w/ our new knowledge on the passive sign convention, we can now talk a fairly simple concept, as long as you get your signs right.

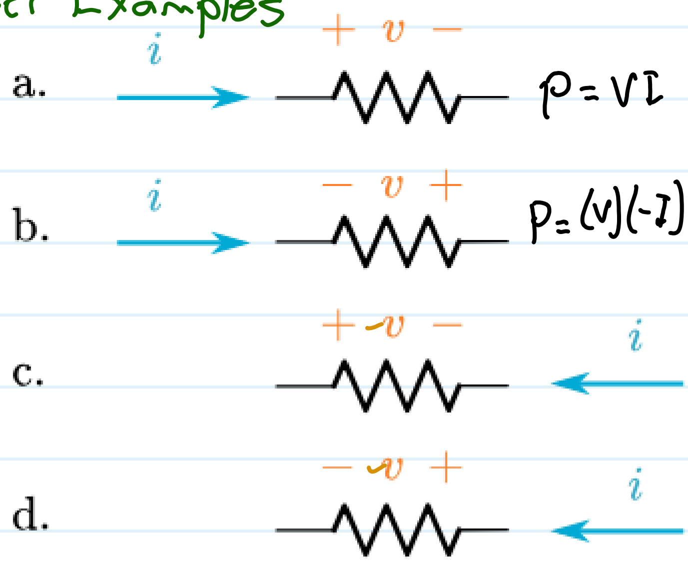
Power is the amount of work done per unit time. If voltage is the work done per amount of charge and current is the amount of charge visiting an area per second, can you think of a way to combine them to get power, which is the amount of work done per second. It might be easier to see from their unit defintions!

$$V = J/C, \quad A = C/s, \quad P = J/s$$

Power: $P = VI = \left(\frac{J}{C}\right)\left(\frac{C}{s}\right) = \frac{J}{s}$

Its important to note that power follows the PSC. Remember, a voltage drop is positive, that means energy being "removed" from the circuit is given a positive sign, and the same follows for power, dissipation (removal) is positive, and delivery (addition) is negative. On the next page are a few examples of how power works

Power Examples



a. $P = VI$ $(+)(+) = (+)$.
Positive Power = Dissipation

b. $P = (V)(-I)$ $(+)(-) = (-)$
Negative Power = Delivery

c. $P = (-V)(-I)$; $(-)(-) = (+)$
Positive Power = Dissipation

d. $P = (-V)(I)$; $(-)(+) = (-)$
Negative Power = Delivery

Do note, all of this was discussed before ever showing a single "real" component, because they apply to everything. Keep this in mind later on.

The Basic Circuit:

Considering this course is called circuit analysis, we're gonna deal with a lot of circuits, but lucky for us, we're (generally) going to be dealing with a special kind of circuit called "lumped, linear, time-invariant" which are some special terms that describe everything but the source

Lumped - The components act like a "point", where once you pass it, the properties of the circuit are immediately changed

Linear - For <u>every single component</u> in the cuircuit, voltage is directly porportional to current ($V \propto I$)

This looks like a formula we're about to learn about...

Time-Invariant - The properties of the circuit do not vary w/ time. This isn't true once we hit AC power.

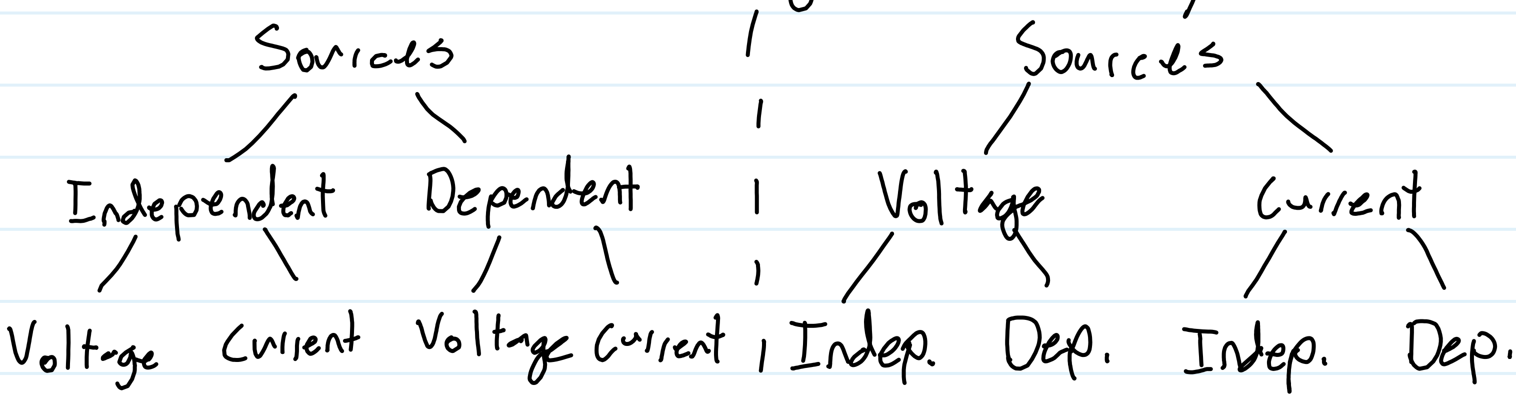
Our circuits will also have 2 types of components: passive and active

Passive - Components that do not generate power. They only get done to

Active - Components that deliver power to the circuit

Sources:

There are a total of 4 types of sources, but the relations between them can be thought of in 2 ways:



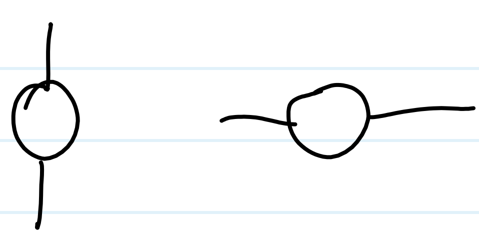
Big trees are scary, but when you come across a source you just have to ask yourself:

1. Independent or Dependent?
2. Voltage or Current?

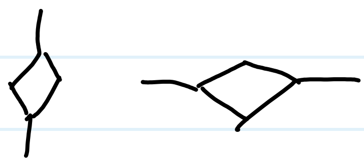
But regardless of the type, a source <u>adds</u> something to a circuit.

Independent or Dependent?

Independent sources are the easy ones, they spit out a value and just continue to spit out the <u>same</u> <u>value</u> forever and ever. Their circuit symbol is:



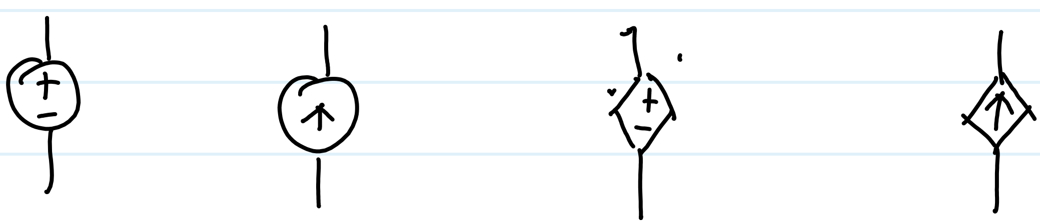
Dependent sources are more tricky, their output is based on another part of the circuit. They may be either current controlled <u>or</u> voltage controlled by some factor: Out = Constant • Controlling variable. the output changes as it is dependent on other elements in the circuit. Their circuit signal is:



Current or Voltage?

There isn't too much fanciness going on here. Current sources supply a current to the circuit. Voltages supply a voltage.
Current is shown using an arrow in direction of flow "$\rightarrow$"
Voltage is shown using a plus and minus for high and low "+ −"

Wrapping it all up, our 4 types of sources are shown below:



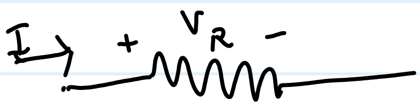
Ind. Voltage Ind. Current Dep. Voltage Dep. Current

↓

$V = \alpha \, i_\Delta$ would be current controlled
$V = \alpha \, V_\Delta$ would be voltage controlled

Resistor:

There's much less going on with this guy than their was with the sources. There's only 1 type of resistor in our circuit. It's circuit symbol is:



Capacitors don't do much, they just dissipate power. Their polarity isn't set, it's drawn using the PSC.

But, This is our first real circuit element. Now it's time to introduce our first component equation. This equation is vital to alot of things we do in this class, and it is!

Ohm's Law: $V = IR$

Where:

V = Voltage across resistor, not the voltage at one terminal (V)
I = Current through resistor (A)
R = Resistance value (Ω)

Do you remember earlier when we discussed the definition of a "linear" component? Where the relationship and voltage and current needed to form a linear graph? I gave you a general equation $V = \alpha I$ to summarize it, can you see how ohm's law (and the resistor it describes) is a linear device? R is our constant of porportionality

The last thing to mention about resistors, is that ohms law gives us a few additional ways to calculate the power dissipated by the resistor:

Resistor Power:

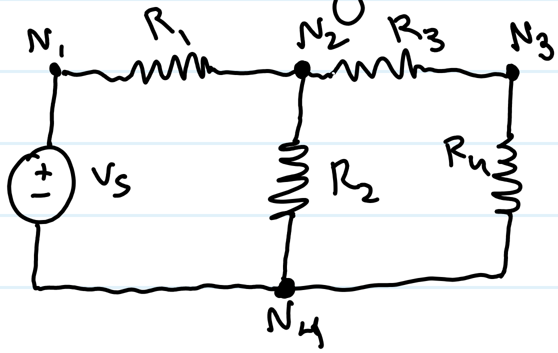
$P = VI$: This is the standard equation for power

$V = IR$; $P = VI \Rightarrow P = (IR)I \Rightarrow P = I^2R$: Power only knowing current

$V = IR \Rightarrow I = \frac{V}{R}$; $P = VI \Rightarrow P = V(\frac{V}{R}) \Rightarrow P = \frac{V^2}{R}$: Power only knowing voltage

Circuit Parts:

For this last portion on the basics of a circuit, lets take a look at the following:



5 Branches: B_{12}, B_{14}, B_{23}, B_{24}, B_{34}

4 Nodes: N_1, N_2, N_3, N_4

3 Loops: L_{124}, L_{234}, L_{1234}

2 meshes: L_{124}, L_{234}

There are a few parts to be able to identify here!

- **Node** - A point in the circuit connecting 2 or more components
- **Branch** - A circuit element or path that connects 2 nodes
- **Essential Node** - A node connecting 3 or more branches
  - N_2 & N_4 are essential nodes
- **Essential Branch** - The path, that may be made of multiple branches, that connects 2 essential nodes without passing through any other essential nodes
  - B_{214}, B_{234}, B_{24} are all essential branches

Loop - A closed path in the circuit

Mesh - A loop in the circuit that does not contain any sub-loops

Reference Node - The node that all other potentials are measured against. For simplicity, it's usually chosen to be the node with a lot of things connected to it.

In our diagram N_4 is most likely to be the reference node

In addition, there's two important types of connections to be aware of and understand

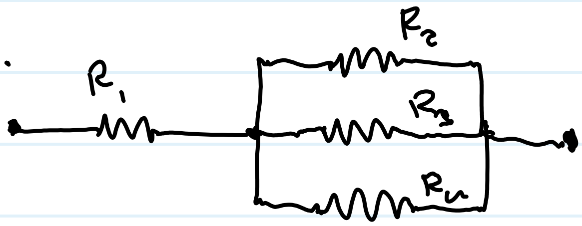
Series - Two components are in series if they share one node, and have no other branches coming from that node.

R_3 & R_4 are in series

R_1 & R_2, R_1 & R_3 are not.

Parallel - Two or more components are said to be in parallel if they share both of their nodes. Other components can (and probably should) branch from these nodes.

R_2 & R_4 are not in parallel, but if we replaced R_3 with a wire they would be.



In the above diagram, R_2, R_3, & R_4 are all in parallel.

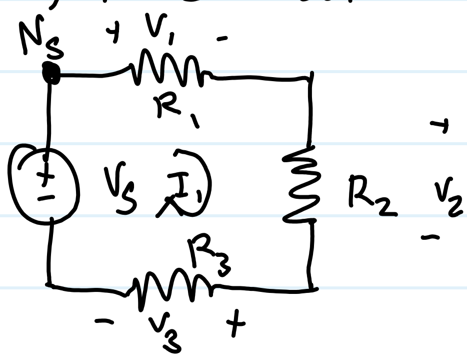
It's important to note, in something like:

there is no series or parallel connections.

Kirchoff's Laws:

In the 1800's Gustav Kirchoff, at the age of 21, published a paper that contained two now incredibly famous equations. He was studying mathematical physics, and thanks to his work, our jobs of circuit analysis are much easier.

The first one we're going to discuss is Kirchoffs Voltage Law (KVL). I'm going to wait to give that a formal definition, because that would be too easy, and would take all the fun out of an intuition. While you wait, take a look at the circuit below:



Since V_S is delivering a voltage to the circuit, we can assume that all of our nodes have some voltage. For our purposes, lets assume $V_S = 5\,V$, $V_1 = 1\,V$, $V_2 = 2\,V$, $V_3 = 3\,V$. Now lets go around the loop repeatedly, summing the voltages while following the PSC.