Intro to ECSE Class 7 Lecture Notes 1/31/23

Terminology & Basic Quantities

1) **Charge**: electrons have charge (think static electricity)
   - ↳ units: Coulombs (C)
   - ↳ variable: Q or q
   - ↳ most fundamental physical quantity in a circuit

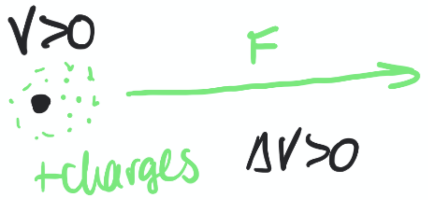
2) **Current**: moving charge (flow of charge)
   - ↳ units: Amperes (A) = $\frac{\text{Coulombs}}{s}$ (charge per time)
   - ↳ variable: I
   - ↳ terminology:
     - Current flows: "through" an element (like a resistor)
       "into" or "out of" a location (i.e. node)
   - ↳ Mathematical definition: $\frac{\Delta \text{charge}}{\Delta \text{time}} = \frac{dQ}{dt} = I$

· But how do get charge to move?

3) Voltage: what puts our system into action ~ force
   - ↳ units: Volts (V)
   - ↳ terminology:
     Voltage: "across" an element (i.e. resistor)
     "at" a location (i.e. node)
   - ↳ Note: Voltage must be measured between two different points: it is always a difference
   - ↳ mathematical definition: $\frac{\Delta \text{potential energy}}{\Delta \text{charge}} = \frac{du}{dQ} = V$

     or $V \cdot \Delta \text{charge} = \Delta \text{potential energy}$

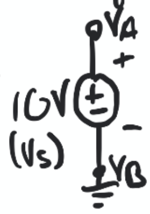
What does this mean?



4) Ground: our reference point for all voltages: $V_{Gnd} = 0$

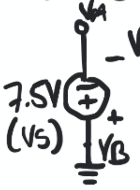
↳ symbols: 

↳ All voltages in a circuit are referenced to some other voltage → ground is our standard reference

↳ 

$V_s = V_A - V_B = V_A > 0$

$V_B = 0$



$V_B - V_A = 0 - 7.5V = -7.5V$
$= V_s$

5) Power: the work done by a circuit

↳ units: Watts (W) = Joules/second

↳ terminology:

Power: "dissipated" (used up) by an element (i.e. resistor)

"delivered" to an element

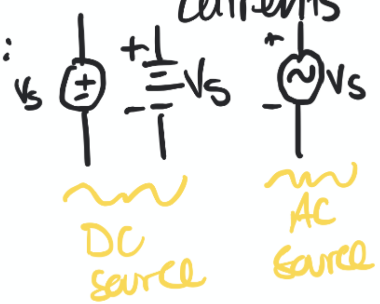
Note: always in reference to some circuit element

↳ mathematical definition: $P = \frac{\Delta energy}{\Delta time} = \frac{dE}{dt}$

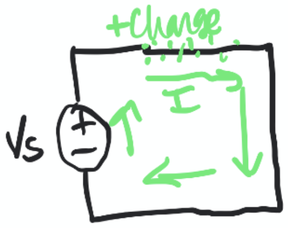
6) Basic Circuit Elements

We have a wire with charge in or on it and we want to make it move: what do we need? a source

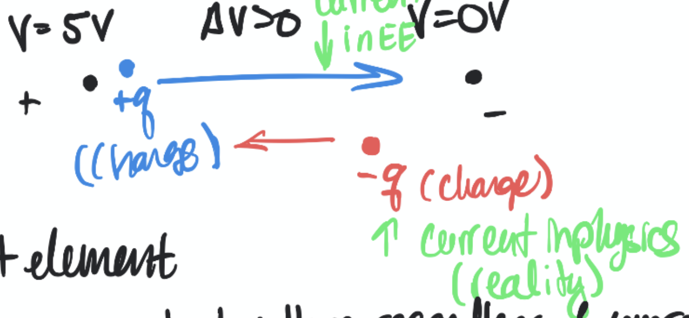
a) Voltage Source: provides a constant voltage at any/all currents

↳ symbol: 

↳ use: provide a force to make charge move (current)

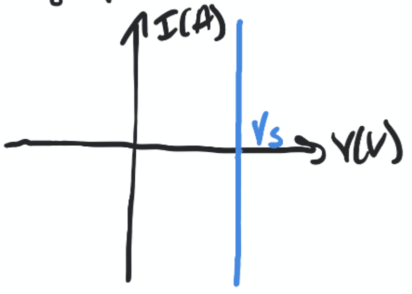


puts the system into action!



↳ I-V Characteristic

: "fingerprint" of circuit element



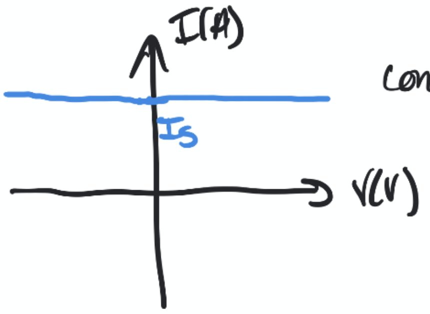
· constant voltage regardless of current

b) Current Source : provides a constant current for any/all voltages

↳ symbol :

arrow points in the direction of current flow

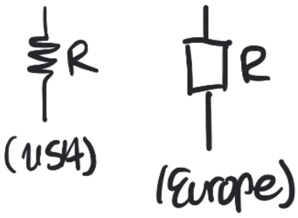
↳ I-V Characteristic



constant current regardless of voltage

c) Resistor : allows us to control current for a given voltage or vice versa

↳ symbol:

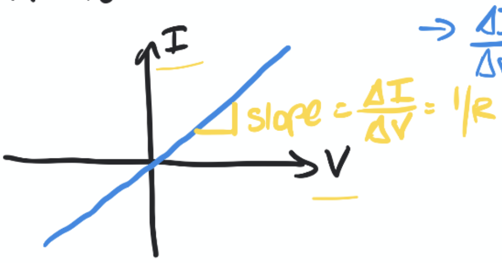


↳ units: Ohms (Ω) = $\frac{\text{Volts}}{\text{Amperes}}$

↳ I-V characteristic

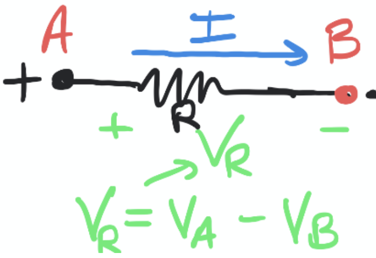
$V = IR \rightarrow \Delta V = \Delta I \cdot R$

$\rightarrow \frac{\Delta I}{\Delta V} = 1/R$



7) Passive Sign Convention

- In electrical engineering current flows from + to − (Voltage)



} this must match

8) KCL | KVL | Ohm's Law

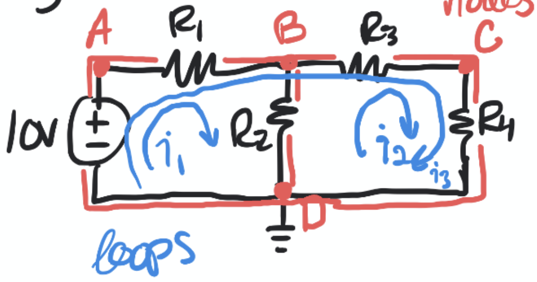
a) Nodes and loops

1) what is a node?

Any connection point between any number of elements

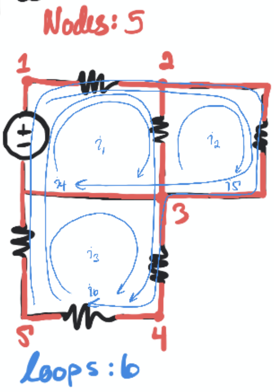
a) What is a loop?

Any enclosed circle in a circuit.



wires have $R=0$, so ΔV across a wire is zero
- all points connected by only a wire have the same voltage

Example:



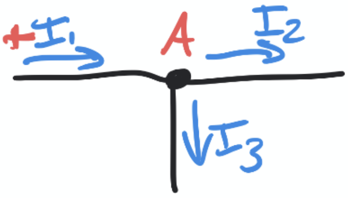
How many nodes? 5

how many loops? 6

b) Kirchoff's Current Law (KCL)

- conservation of charge: all current entering and exiting a node must sum to zero

Define: · current entering a node gets a "+" sign
- current exiting a node gets a "−" sign



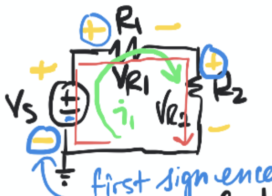
$+I_1 - I_2 - I_3 = 0$

$I_1 = I_2 + I_3$

current entering — current leaving

c) Kirchoff's Voltage Law (KVL)

- conservation of energy: all voltages in a loop in a circuit must sum to zero



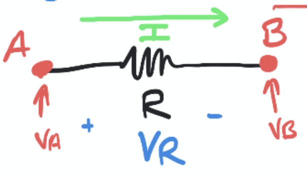
$i_1: -V_s + V_{R1} + V_{R2} = 0$

$V_s = V_{R1} + V_{R2}$

- Voltages get the sign of the first "+" or "−" encountered moving in the direction of the loop in the circuit

d) Ohm's Law: Relates voltage, resistance, and current

$\Delta V = IR = V_A - V_B = V_R$

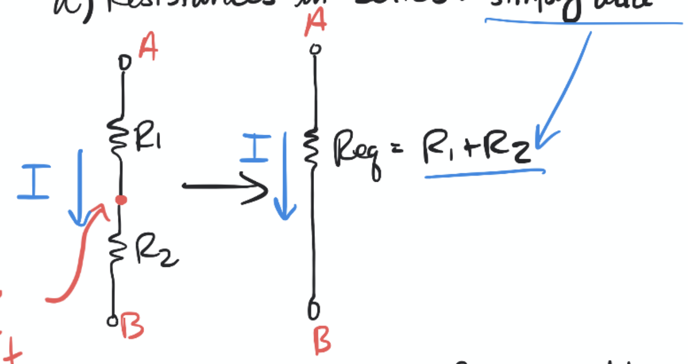


↑ corresponds to direction of current flow

End of lecture

9) Combining Resistances: have one common node with no other elements sharing it

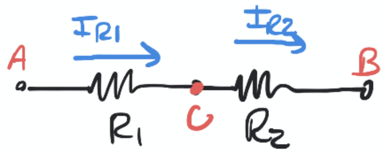
a) Resistances in Series: simply add



one common node not shared with other elements

Note: the current flowing through elements in series is the same

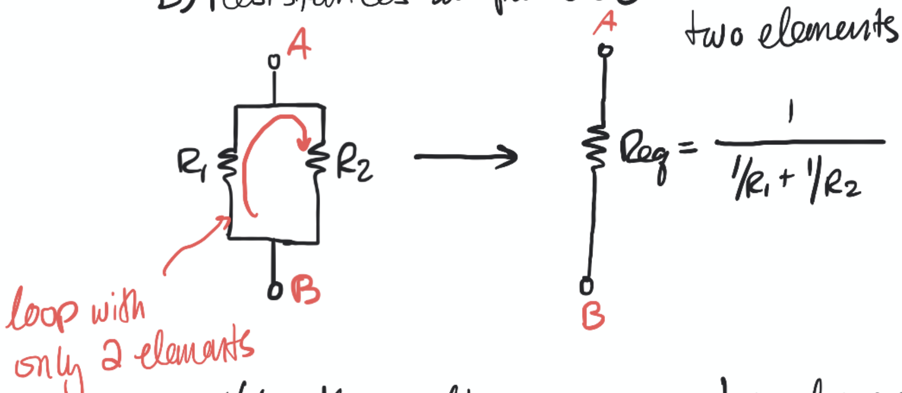
i.e.



due to KCL, at node C: $I_{R1} - I_{R2} = 0$,

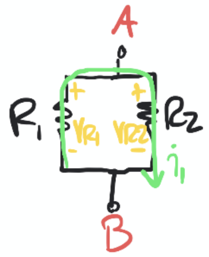
so $I_{R1} = I_{R2}$

b) Resistances in parallel: form a loop with only two elements



reciprocal resistances add and then the reciprocal of the sum is taken

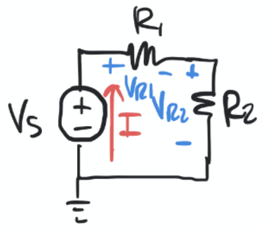
Note: the voltage across two elements in parallel is the same



KVL: $-V_{R1} + V_{R2} = 0$

so $V_{R1} = V_{R2}$

10) Voltage Divider: In a series circuit with a voltage source V_s, the voltage gets divided between the resistors proportional to the ratio of the resistor's resistance to the total series resistance



Let's find V_{R1}:

i) $V_{R1} = I R_1$ (Ohm's law)

ii) What is I? In a series circuit, I is the same through all components,

so $I = \frac{V_s}{R_1+R_2}$ (Ohm's law)

iii) Plug in I

$$V_{R1} = IR_1 = \frac{V_S}{R_1+R_2} R_1$$

So $V_{R1} = V_S \frac{R_1}{R_1+R_2}$

Source voltage → V_S

resistor whose voltage drop we're measuring → R_1

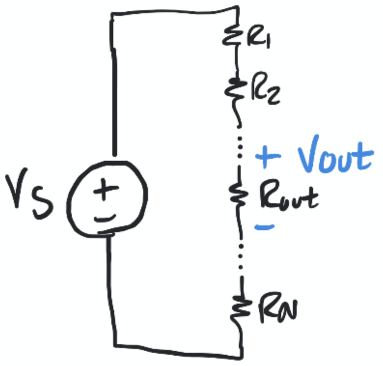
Voltage across R_1 → V_{R1}

total series resistance → $R_1 + R_2$

Voltage divider equation

$$\text{So } V \text{ across } R_1 = \text{Source Voltage} \cdot \frac{R_1}{\text{total series resistance}}$$

If we have a series circuit with "N" resistors and we want to know the voltage across one of them:



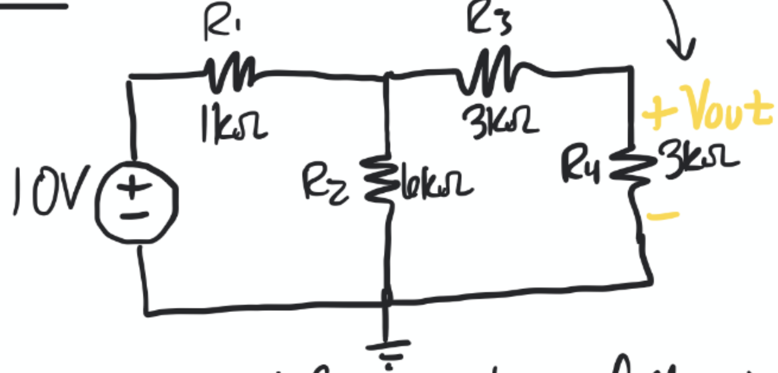
$$V_{out} = V_S \frac{R_{out}}{\sum_{i=1}^{N} R_i}$$

total series resistance ($\sum_{i=1}^{N} R_i$)

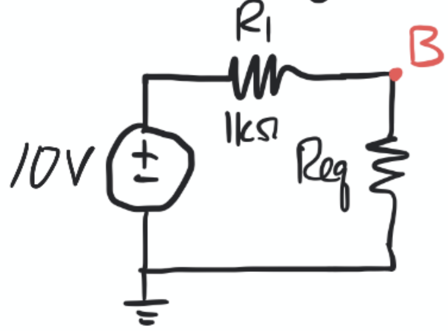
11) Circuit Analysis Technique: Circuit Reduction

→ Strategy: Combine series and parallel resistances until we have a circuit that is solvable via a voltage divider or Ohm's law, then work backwards to find the desired quantity

Example: Find $V_{R4} = V_{out}$



goal: simplify to the following circuit via combining resistances



· then use voltage divider to find voltage at B, then use Ohm's law or voltage dividers as needed to find V_{R4}.

Try this before next class!