

Circuit Lab

Division B/C

Georgia Tech Event Workshop Series
2025-26

Science Olympiad
at
Georgia Tech[®]



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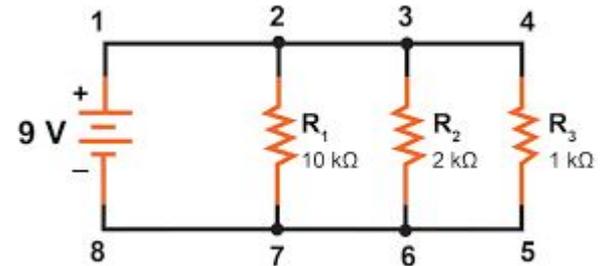
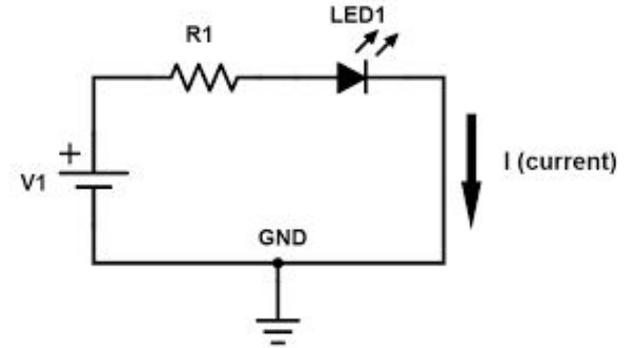
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The Rules Sheet

- Lab Event: You'll have both a test and a Lab portion to complete
- Test: Focuses mainly on circuits, both conceptually and quantitatively. Includes topics like voltage, current, resistance, capacitance, etc.
- Lab: Real-life application of circuit concepts. Can ask you to do any number of things and tests you on your familiarity with components and how they work



CIRCUIT LAB C

See General Rules, Eye Protection & other Policies on www.soiac.org as they apply to every event.



- DESCRIPTION:** Participants must complete tasks and answer questions about electricity and magnetism.
TEAM OF UP TO: 2
APPROXIMATE TIME: 50 minutes
CALCULATOR: Class III
- EVENT PARAMETERS:**
 - Each team may bring a collection of notes and resources, written/printed on paper, of any size containing information in any form and from any source. Binders, notebooks, folders, sheet protectors, lamination, tabs, and labels are permitted. Participants are responsible for organizing and containing their notes efficiently. They may separate or remove the pages from containers for use during any part of the event
 - Each team may also bring writing utensils and two Class III calculators for use during any part of the event.
 - Event Supervisors must provide all supplies and measurement devices required for the hands-on tasks.
 - Participants may bring their own basic multimeters for use in place of provided ones at the discretion of the Event Supervisor.
- THE COMPETITION:**

Part I: Written Test

 - The written test will assess the team's knowledge of electricity and magnetism.
 - Unless otherwise requested, answers must be in metric units with appropriate significant figures.
 - The test will consist of at least one question from each of the following areas only:
 - Properties of electric charges/fields, sources/hazards of static electricity, Coulomb's Law, capacitance
 - Direct current (DC) characteristics, sources, uses, DC hazards
 - Alternating current (AC) characteristics, sources, uses, AC hazards, common household AC components
 - Concepts and units of current, voltage, resistance, power, energy, and using Ohm's law
 - Magnetic poles/fields, electromagnets, transformers, motors/generators, right-hand rule
 - Electrical control devices including switches, relays, fuses, ground fault circuit interrupters, and breakers
 - Simple calculations, constructions, and configurations of a circuit and individual components, including simple circuit diagrams
 - Simple circuit analysis using Kirchhoff's Voltage & Current Laws
 - Historical perspective of the electricity and magnetism discoveries made by Ampere, Coulomb, Kirchhoff, Volta, Ohm, Tesla, & Faraday
 - States/Nationals only:
 - Fundamental characteristics and operation of a light emitting diode (LED)
 - Basic electrical characteristics of silicon PN junctions (e.g., Diodes, PNP, NPN)
 - Basic operating principles and applications of Operational Amplifiers (op-amps)
 - Topics not included in the competition are: semiconductors (beyond those listed above), AC circuit theory, frequency analysis, inductance, calculations involving direct use of calculus and/or differential equations, non-linear devices, 3 Phase Power, and oscilloscopes.

Part II: Hands-On Tasks

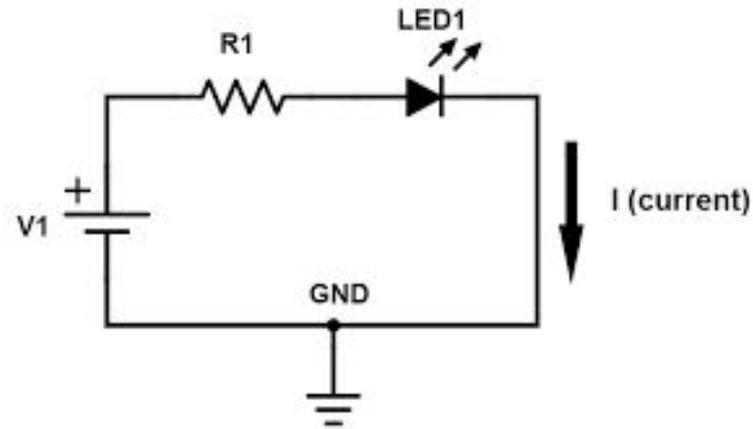
 - The hands-on portion will consist of at least one task for the teams to complete.
 - Participants must be familiar with the operation of breadboards and multimeters and how to use them. Participants may ask Event Supervisors for details of the internal wiring of any breadboards used for the tasks.
 - The hands-on tasks, or stations, may include but are not limited to:
 - Determine the value of a mystery resistor in a circuit using only voltage measurements.
 - Calculate the power supplied to a circuit.
 - Given some wires, batteries, resistors, and 2 LEDs, hook them up so the LEDs are equally bright.
 - Construct an electromagnet using some wire, a bolt and battery.
 - Given a USB charger, read the label and provide details of the various output power levels it can provide and calculate how long it would take to charge a specific battery.



Basics

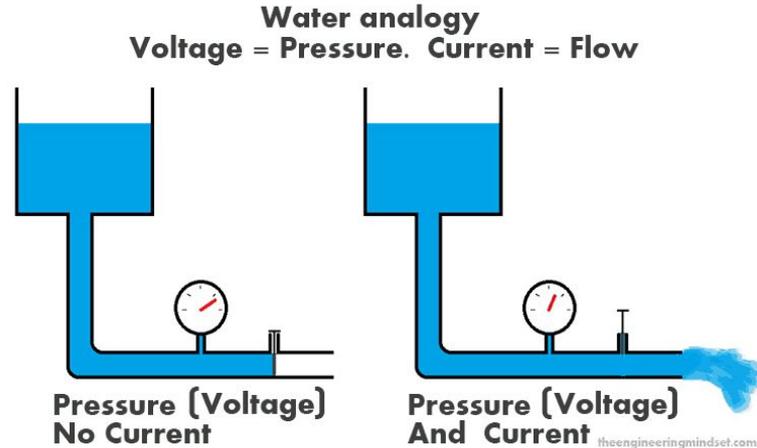
What is a Circuit?

- A circuit is a closed loop that moves electrons through the loop via the use of an electrical energy source.
- These loops are usually made of metal wires that connect the ends of the energy source together.
- A circuit is “broken” when there is no longer a closed path for the electrons to travel, resulting in the flow of electrons being halted.
- Circuits usually have three main qualities: voltage, current, and resistance.



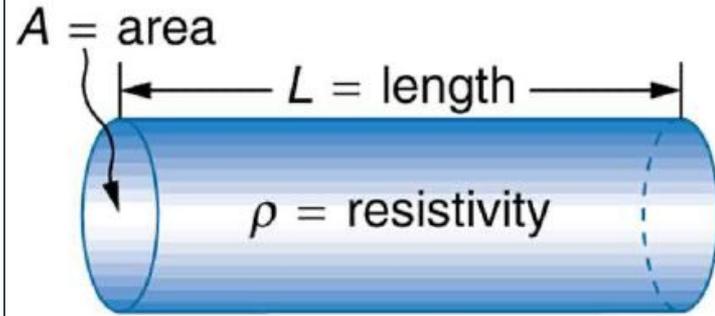
Voltage & Current

- The voltage of a battery describes the difference in energy between the positive and negative terminals of the battery. That difference in energy, is what creates the current that runs through the circuit
- Current is measure of the flow of charge in a circuit.
- You can think of voltage like the water pressure in a tank and current like the flow of water. The higher the pressure, the faster the water flows.



Resistors & Resistance

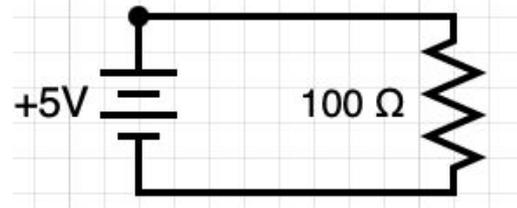
- Resistance is a measure of how much voltage is dissipated by a circuit element when a current is run through it.
- Resistors are circuit elements that only have resistance.
- The resistance of a resistor can be calculated using the formula: $R = \frac{\rho L}{A}$
- ρ is resistivity, a material specific constant, and L and A are length and cross-sectional area of the resistor respectively.
- Usually represented by the zig-zag symbol on the right
- Resistors control how much current there is for a given voltage



Ohm's Law

$$V = IR \quad \text{or} \quad I = \frac{V}{R} \quad \text{or} \quad R = \frac{V}{I}$$

- Describes voltage, current, and resistance in equation form.
- We can use Ohm's Law to find the current of the circuit. $I = V/R = 5/100 = 0.05 \text{ A}$

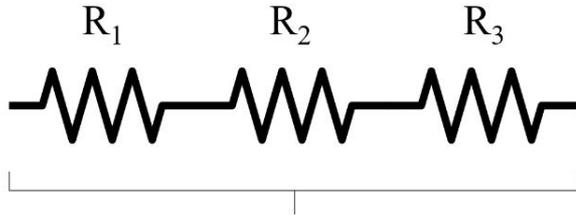


Equivalent Resistance

- Resistors can be configured in multiple ways. Instead of having to think about each resistor independently, we can combine the resistors into one resistor with an equivalent resistance to the whole configuration

Series Resistors

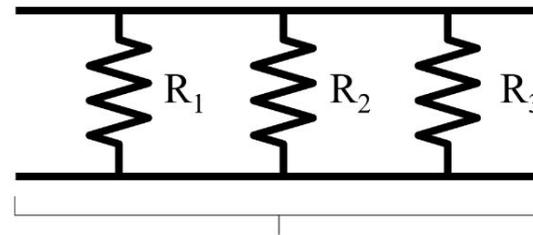
Current is the same across each resistor. Voltage is divided.



$$R_{Equivalent} = R_1 + R_2 + \dots + R_{N-1} + R_N$$

Parallel Resistors

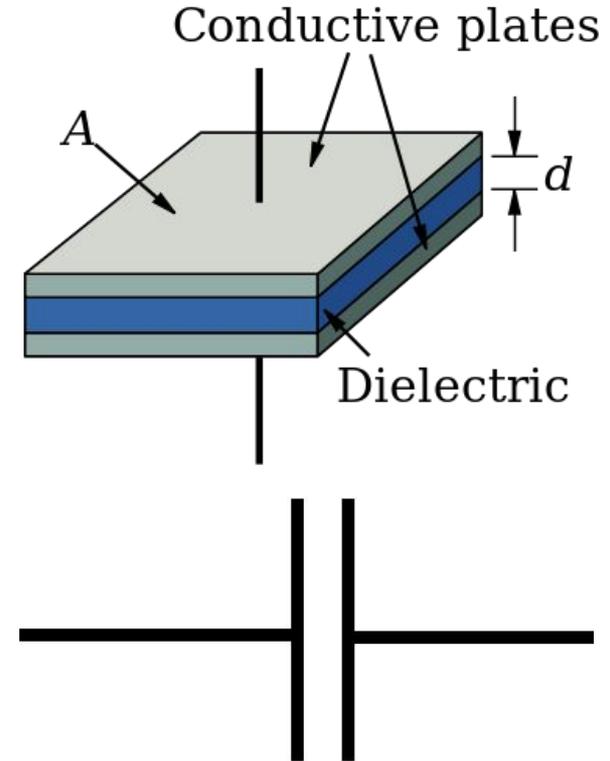
Voltage is the same across each resistor. Current is divided.



$$R_{Equivalent} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_{N-1}} + \frac{1}{R_N}}$$

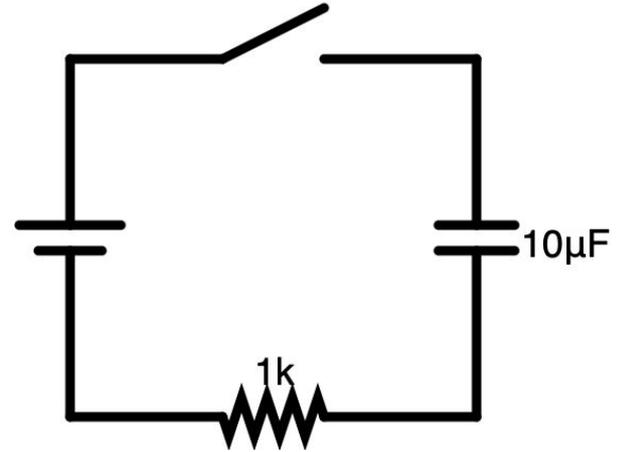
Capacitors & Capacitance

- Capacitance is defined as the amount of charge an element can hold per volt applied to the element.
- This can be expressed as $C = Q/V$ where C is capacitance, Q is charge, and V is voltage.
- A circuit element that has only has capacitance is called a capacitor.
- The capacitance of a capacitor can be determined by the equation: $C = \frac{\kappa \epsilon_0 A}{d}$
- κ is the material-specific dielectric constant, ϵ_0 is the universal constant vacuum permittivity, A is the area of the capacitor plates, and d is the distance between the plates
- The symbol on the bottom left commonly represents capacitors in circuits.



Capacitors (cont.)

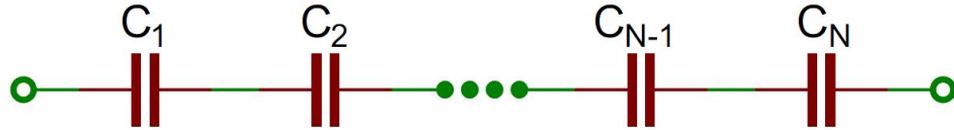
- In circuits, capacitors introduce the dimension of time to our circuit.
- Upon closing the switch, the capacitor will act like a plain wire, letting the current flow as if it wasn't even there.
- As time passes, the battery will charge up the capacitor, giving it a voltage that resists the voltage of the battery. This makes the current decrease.
- After the switch has been closed for a long time, the capacitor will act like an open switch and the current will be zero.



Equivalent Capacitance

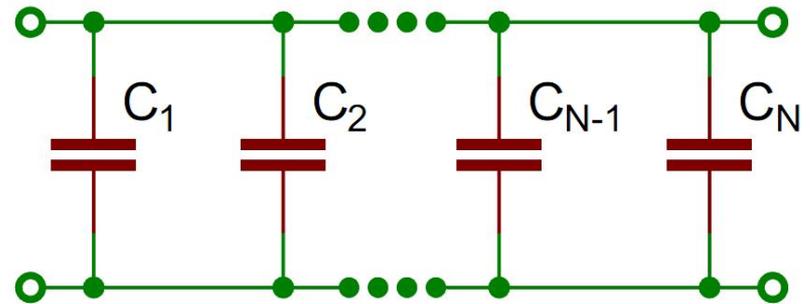
- Just like resistors, capacitors can be configured in multiple ways and simplified into one capacitor, making it easier to understand how a circuit functions.

Series Capacitors



$$\frac{1}{C_{Tot}} = \frac{1}{C_1} + \frac{1}{C_2} + \dots + \frac{1}{C_{N-1}} + \frac{1}{C_N}$$

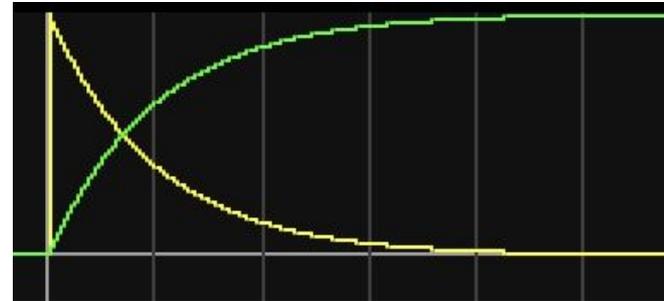
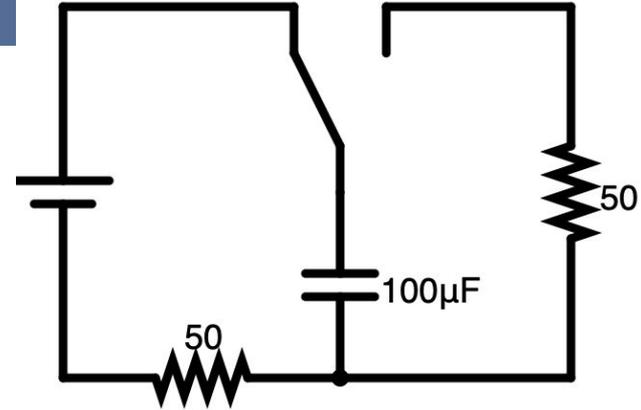
Parallel Capacitors



$$C_{Tot} = C_1 + C_2 + \dots + C_{N-1} + C_N$$

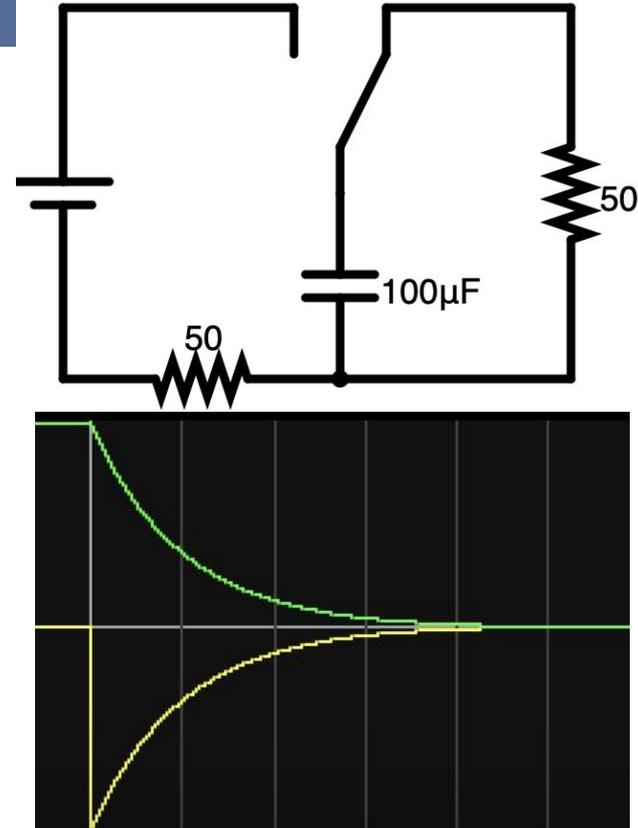
RC Circuits (Charging)

- At $t=0$, the switch is closed, and current starts flowing through the left loop. The current is equal to the current of the system if there was no capacitor, and the voltage of the capacitor is zero.
- As time passes, the voltage across the capacitor increases, counteracting the voltage of the battery. This causes a decrease in the current of the circuit.
- As t approaches infinity, the voltage of the capacitor approaches the voltage of the battery and the current of the circuit approaches zero.
- The yellow graph depicts the current and the green graph depicts the voltage of the battery as time passes.



RC Circuits (Discharging)

- Once the capacitor is fully charged from the previous example, the switch is flipped at $t=t_0$, discharging the capacitor.
- The current of the loop jumps to the maximum current possible for the circuit and the voltage starts decreasing.
- As the voltage decreases, there is less energy causing the current, making the current decrease in magnitude as well.
- After a long time, the capacitor has fully discharged, leaving both voltage and current at zero.



The image features a grid of windows, possibly in a modern office or data center, with a blue background. Each window pane is filled with a pattern of white binary code (0s and 1s). A semi-transparent blue rectangular box is centered over the grid, containing the text "Advanced Topics" in white. The overall aesthetic is clean, technical, and futuristic.

Advanced Topics

Kirchhoff's Voltage Law

- Also known as: KVL, Loop Law
- Says the sum of voltages in a closed loop equals 0.

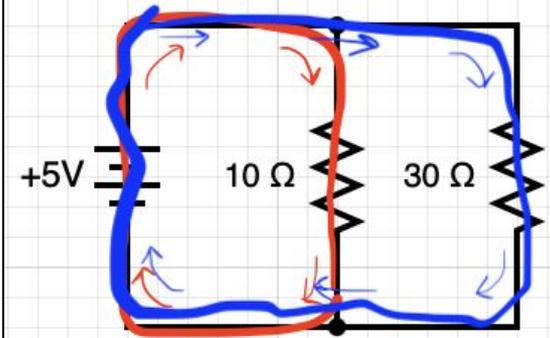
$$\sum V = 0$$

- Ex: Red loop

- $\sum V = V_b - V_{R1} = 0$
- $V_b = 5, V_{R1} = (10)(I_2)$
- $\sum V = 5 - (10)(I_2) = 0$
- $I_2 = 5/10 = 0.5 \text{ A}$

- Ex: Blue loop

- $\sum V = V_b - V_{R2} = 0$
- $V_b = 5, V_{R2} = (30)(I_3)$
- $\sum V = 5 - (30)(I_3) = 0$
- $I_3 = 5/30 = 0.166 \text{ A}$



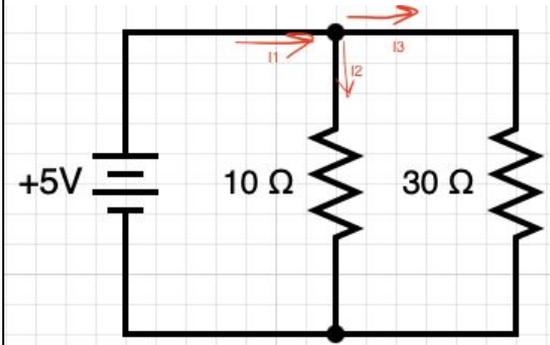
Kirchhoff's Current Law

- Also known as: KCL, Junction Law
- States the sum of currents at a junction equals 0

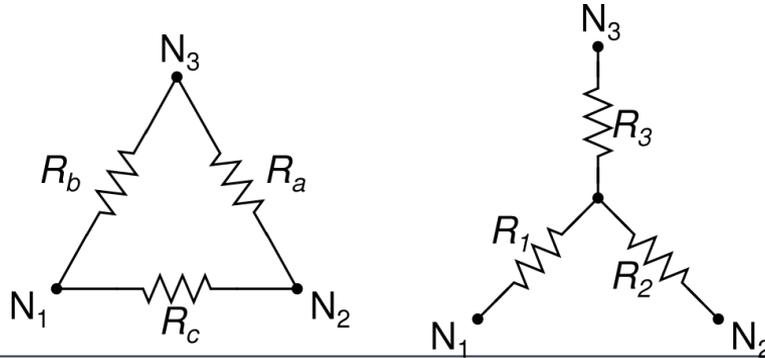
$$\sum I = 0$$

- Example:

- $\sum I = \sum I_{in} - \sum I_{out} = 0$
- $\sum I_{in} = I_1$
- $\sum I_{out} = I_2 + I_3$
- $\sum I = \sum I_{in} - \sum I_{out} = I_1 - I_2 - I_3 = 0 \rightarrow I_1 = I_2 + I_3$
- Using the values of I_2 and I_3 from the previous problem, we get $I_1 = 0.666 \text{ A}$

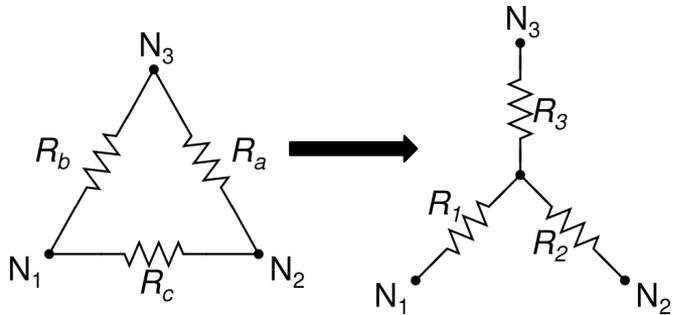


Delta-Wye Transformation



- Not all resistor circuits can be easily simplified using just series and parallel equivalence. The Delta-Wye Transformation helps us simplify circuits that would be a pain to simplify otherwise.
- It has two forms: Delta-Wye and Wye-Delta.

Delta-Wye Transformation

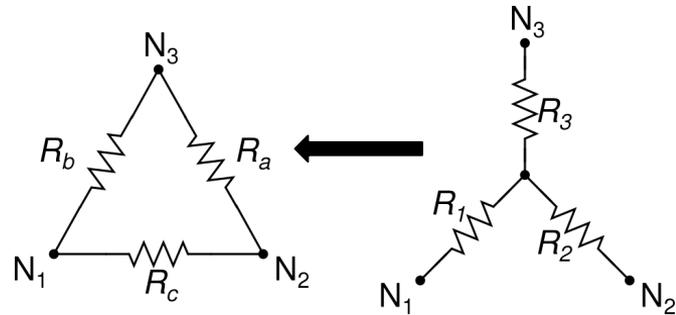


- Delta-Wye Equations:

$$R_1 = \frac{R_b R_c}{R_a + R_b + R_c}$$

$$R_2 = \frac{R_a R_c}{R_a + R_b + R_c}$$

$$R_3 = \frac{R_a R_b}{R_a + R_b + R_c}$$



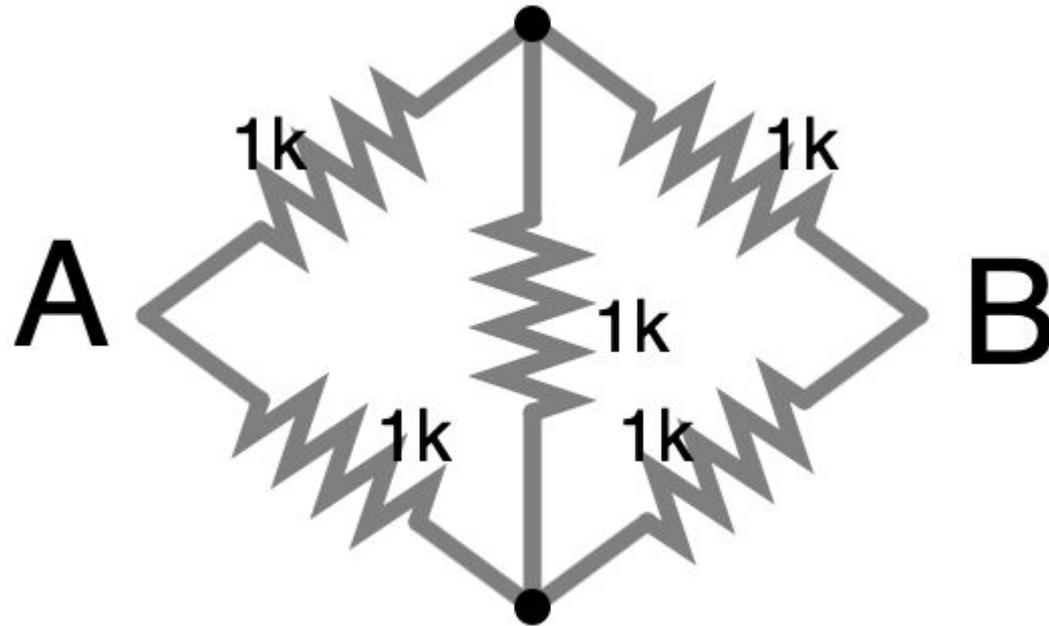
- Wye-Delta Equations:

$$R_a = R_2 + R_3 + \frac{R_2 R_3}{R_1}$$

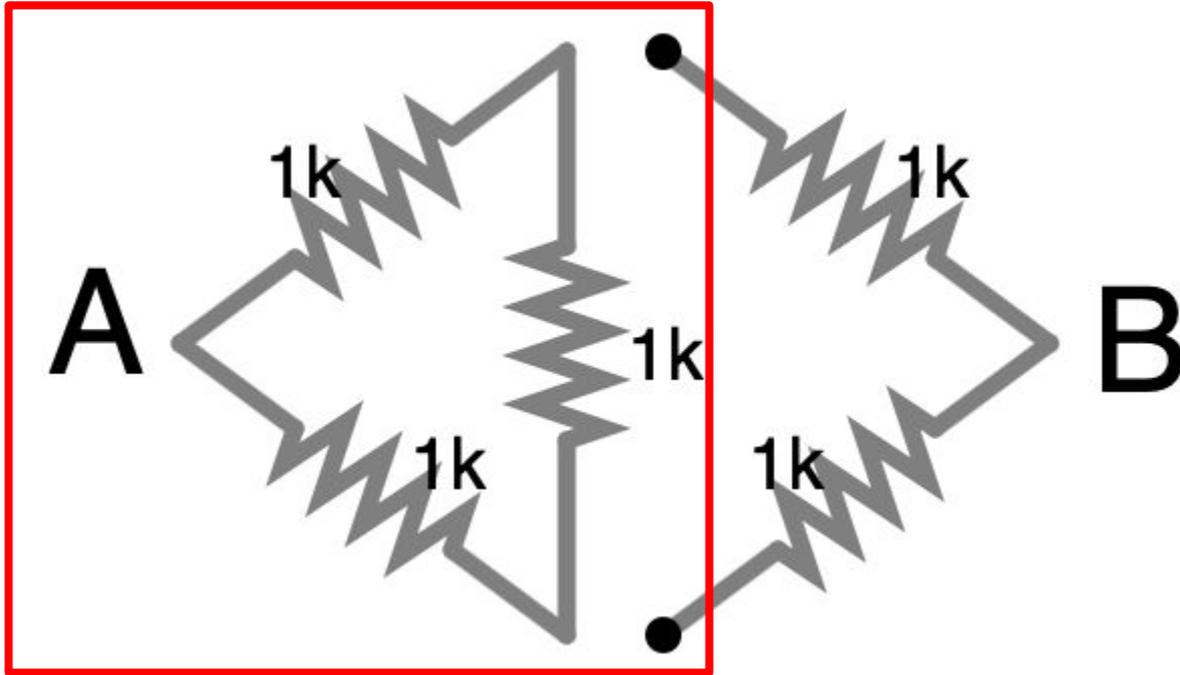
$$R_b = R_1 + R_3 + \frac{R_1 R_3}{R_2}$$

$$R_c = R_1 + R_2 + \frac{R_1 R_2}{R_3}$$

Delta-Wye Transformation



Delta-Wye Transformation

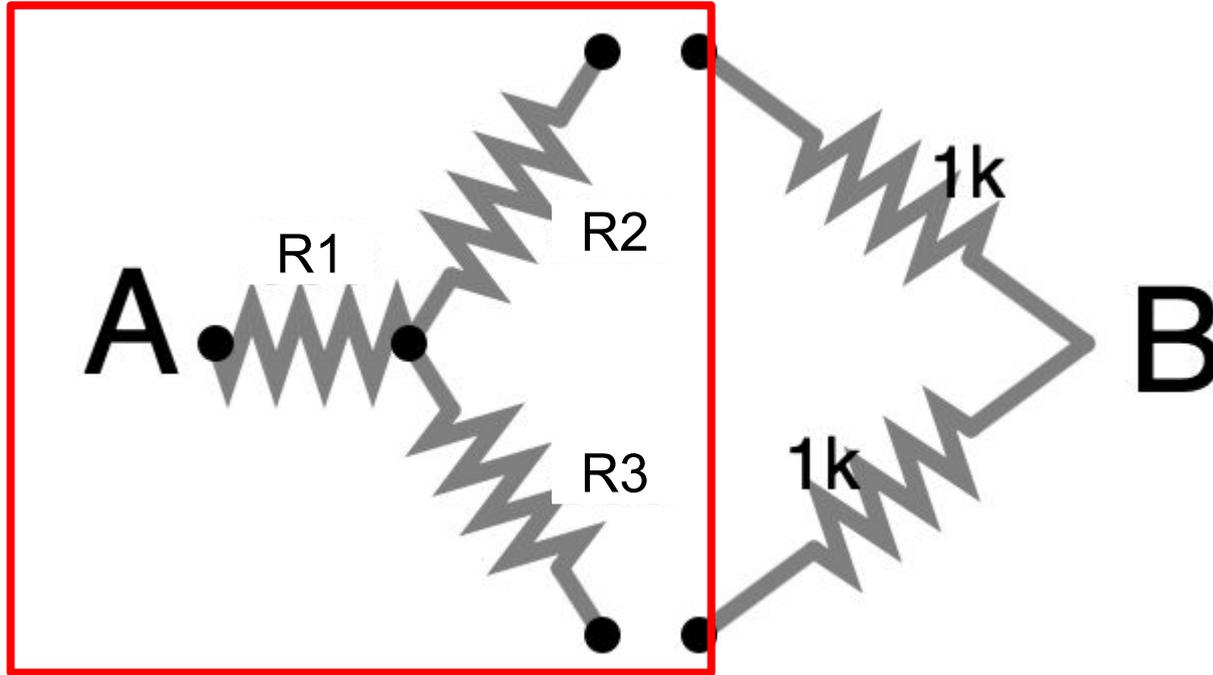


Delta-Wye Transformation

$$R_1 = \frac{R_b R_c}{R_a + R_b + R_c}$$

$$R_2 = \frac{R_a R_c}{R_a + R_b + R_c}$$

$$R_3 = \frac{R_a R_b}{R_a + R_b + R_c}$$



Delta-Wye Transformation

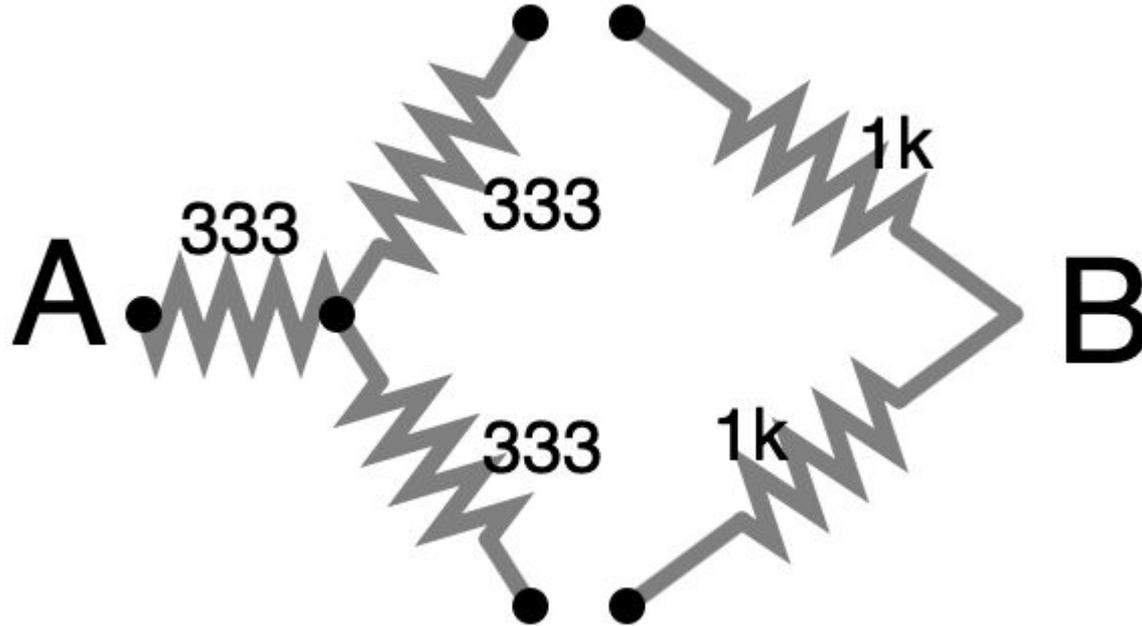
$$R_1 = \frac{R_b R_c}{R_a + R_b + R_c}$$

$$R_2 = \frac{R_a R_c}{R_a + R_b + R_c}$$

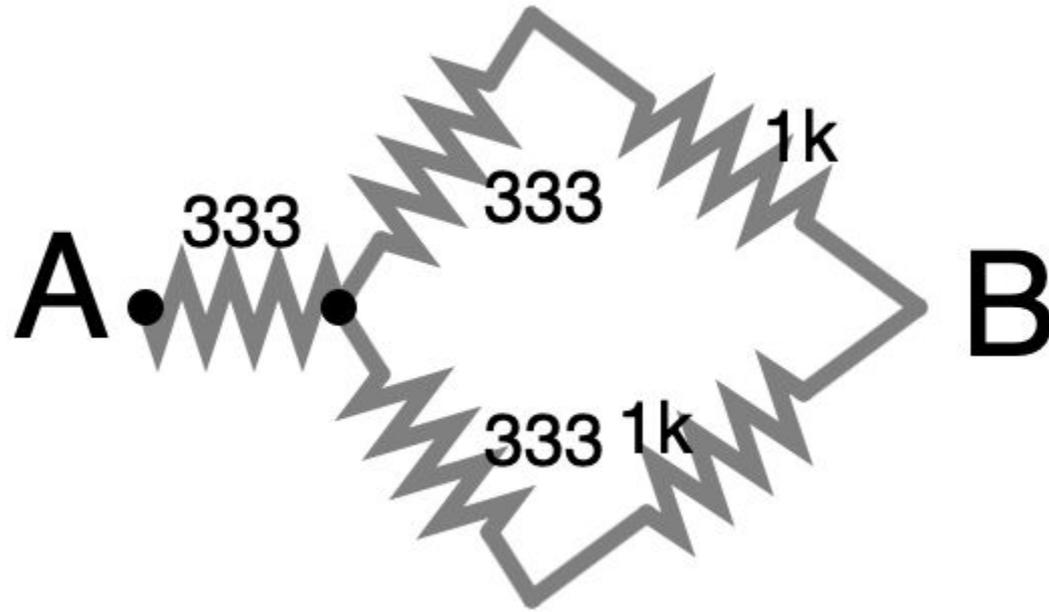
$$R_3 = \frac{R_a R_b}{R_a + R_b + R_c}$$

$$R_1 = R_2 = R_3 = (1k)(1k)/3k$$

$$(1k)(1k)/3k = 1k/3 \sim 333$$

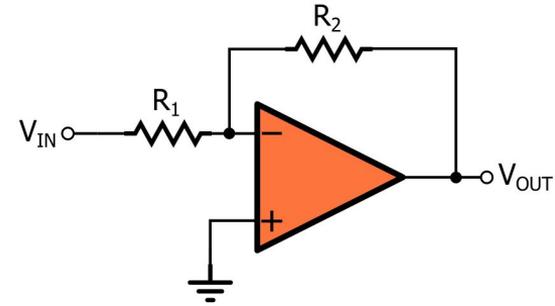
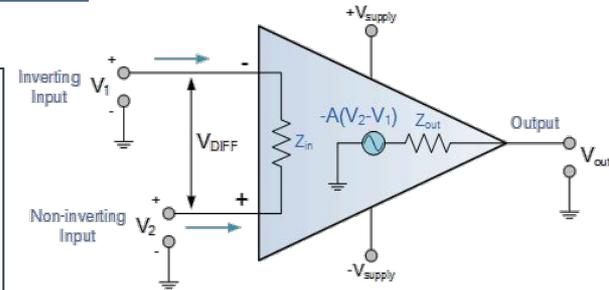


Delta-Wye Transformation



Op-Amps (Div C Only)

- Changes output depending on the configuration
- In open-loop configuration, $V_{out} = A(V_2 - V_1)$, where A is the gain
- In closed-loop configurations, V_{out} changes depending on the specific configuration.
- Ideal op-amps have 4 assumptions:
 - Infinite gain in open-loop configuration
 - Infinite resistance at the inputs
 - Zero resistance at the output
 - In closed-loop configs, inputs are equal



Tips from a Veteran

- Practice Tests:
 - Take lots and lots of practice tests! As the season progresses, more and more invites will publicly release their test sets. Use them! Consistently practicing and learning from those tests is the best way to get better at the test portion.
- Lab Portion:
 - This is where the circuit analysis and component knowledge from the test come into play. Be very familiar with different component configurations as well as analysis methods like Kirchoff's Law.

Additional Resources

AllAboutCircuits.com

falstad.com/circuit

Organic Chemistry Tutor

Scioly Wiki Circuit Lab Page

THANKS!





COMMON QUESTIONS

All of the following questions have been pulled from past Y11 exams (which can be found on our website) or the Text Exchange on SciOly Wiki

Question 1

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Question 2

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Question 3

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