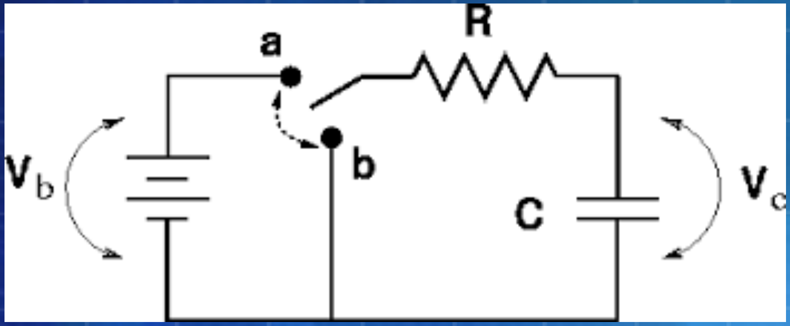
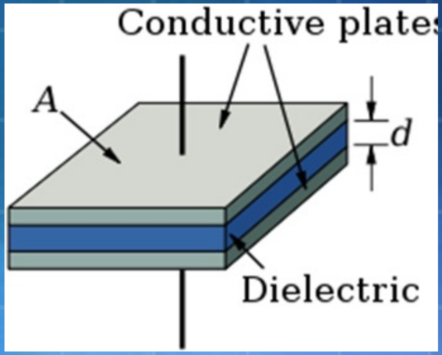
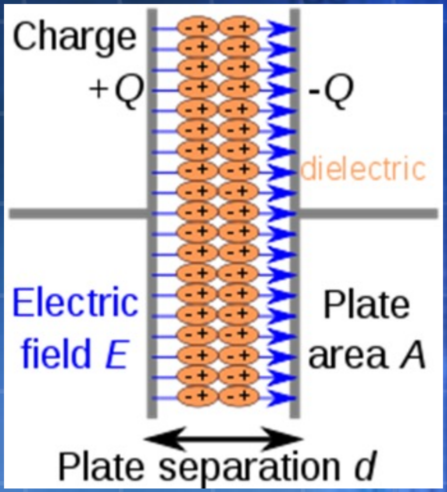






Circuit Lab

Practice #13—RC Circuits

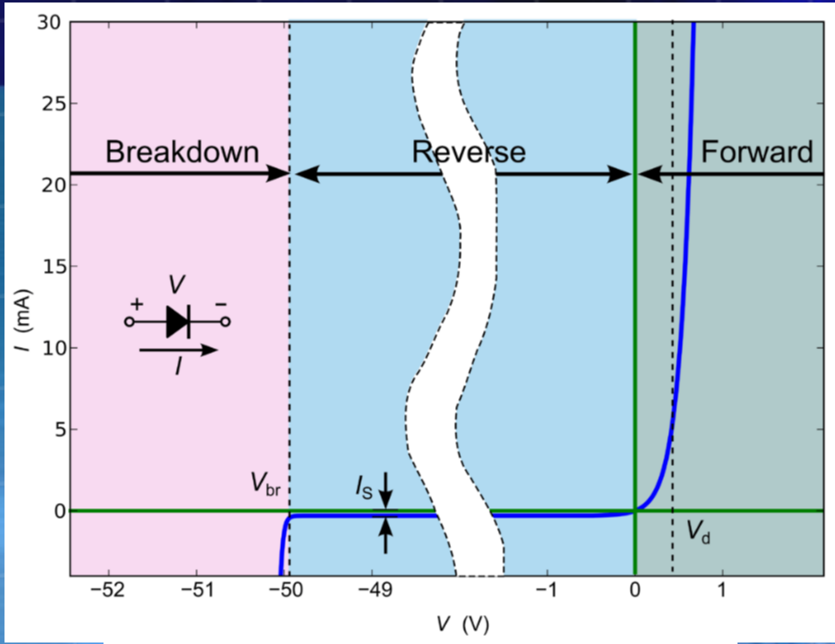
Mr. Burleson
geaux15@hotmail.com

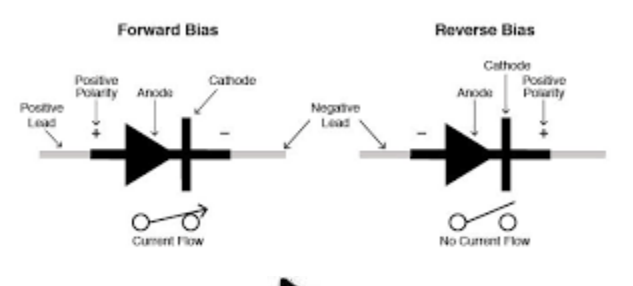
Diode

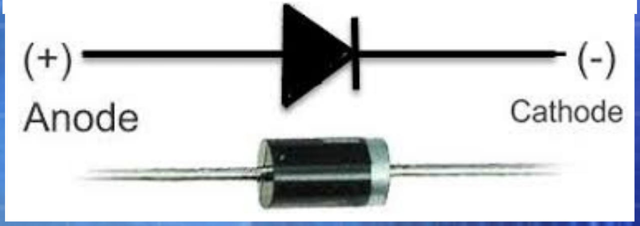
(Division C Only)

- A diode is a two-terminal electronic component that conducts current primarily in one direction (asymmetric conductance); it has low (ideally zero) resistance in one direction, and high (ideally infinite) resistance in the other
- Ideally can be replaced with
  - A short (0Ω) when forward biased or closed switch
  - An open (∞Ω) when reverse biased or open switch
- When forward biased has a small resistance and a bias depending upon semiconductor material
  - 0.6-0.7V for Si Diodes
  - 0.25 to 0.3V for Ge Diodes
  - LEDs can be as high as 4.0V

https://en.wikipedia.org/wiki/Diode

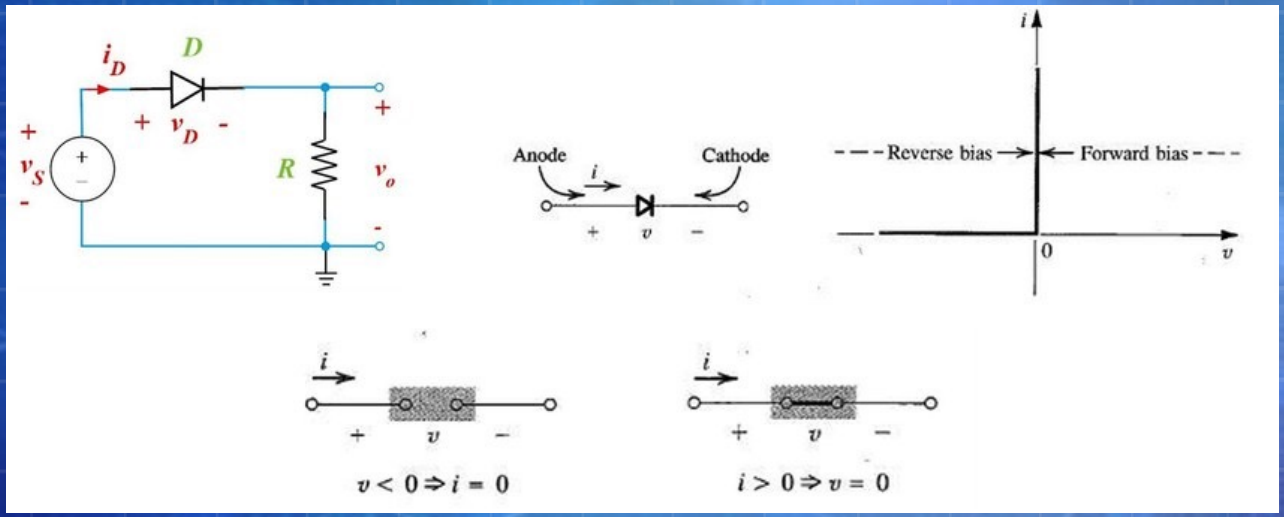






Ideal Diode

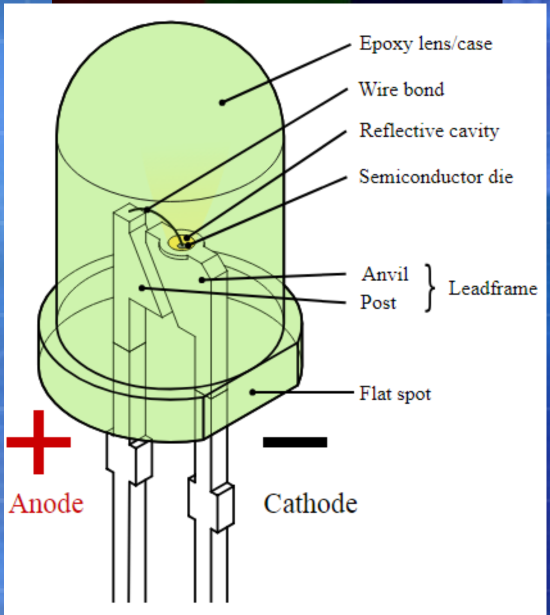
- Ideal diode has zero resistance in Forward Bias with the forward bias voltage and infinite resistance in Reverse Bias.
- Note that normally they assume the bias voltage is for Si ~0.7V
- In Example below:
  - If v_S >= 0.7V, then the diode is in forward bias, no resistance by still account for $v_D = 0.7V$, therefore $v_o = v_S - 0.7V$
  - If v_s <0.7V, the diode is in reverse bias and can be treated as open

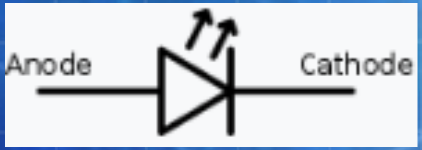


https://www.researchgate.net/figure/A-circuit-with-Ideal-Diode-its-i-v-characteristic-and-equivalent-circuits-in-the_fig12_316098112

Light Emitting Diodes (LEDs)

- A light-emitting diode (LED) is a two-lead semiconductor light source. It is a p–n junction diode that emits light when activated
- Color is determined by the energy band gap of the semiconductor, which also affects the voltage drop
  - Full table has been put in the Homework Generator, LED Datasheet tab
  - https://en.wikipedia.org/wiki/Light-emitting_diode#cite_note-79





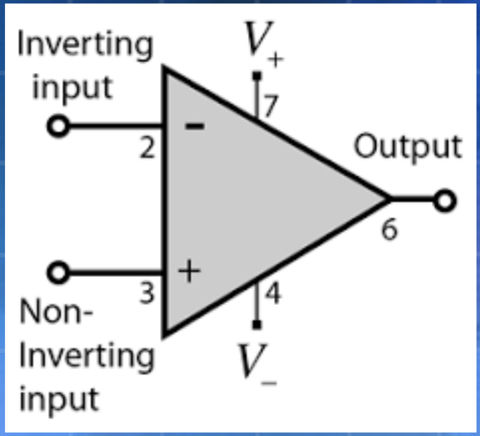
https://en.wikipedia.org/wiki/Light-emitting_diode

Operational Amplifiers

SCIENCE OLYMPIAD
Exploring the World of Science

(Division C Only)

- An operational amplifier (often op-amp or opamp) is a DC-coupled high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output
- Very popular due to its versatility as a differential amplifier.
- Can be set up easily as a comparator, inverting amplifier, or non-inverting amplifier
- <u>NEVER, EVER use a KCL at the output of an Op-Amp</u>

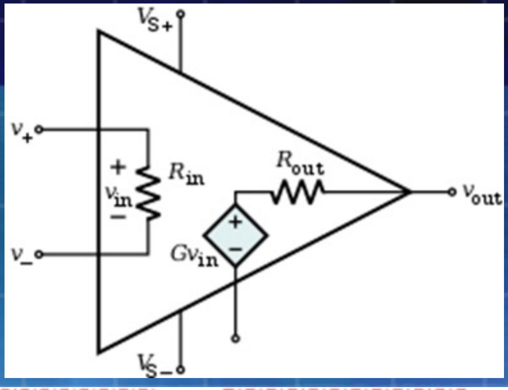


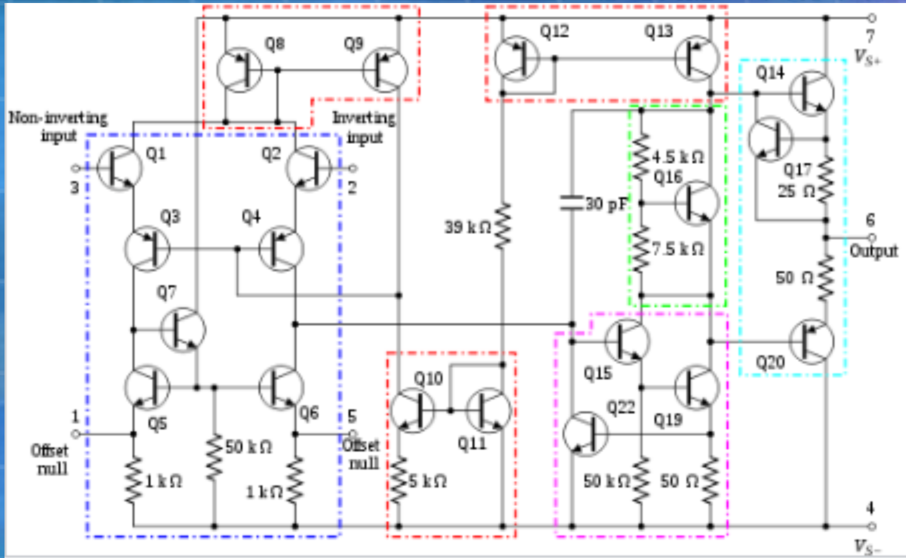
https://en.wikipedia.org/wiki/Operational_amplifier

Ideal Op-Amps

- Full List for Ideal Op-Amps
  - Infinite Open-Loop Gain (G)
  - Infinite Input Impedance (R_{in})
  - Infinite Out Voltage Range (v_{out} max)
  - Infinite Common-Mode Rejection Ratio
  - Infinite Power Supply Reject Ratio
  - Zero Input Offset Voltage
  - Zero Output Impedance (R_{out})
  - Zero Noise
  - Zero Input Current (v_{in}/R_{in})
  - None of these are actual

- Two Golden Rules
  - $V_+ = V_-$
  - Current is zero at V_+ and V_-



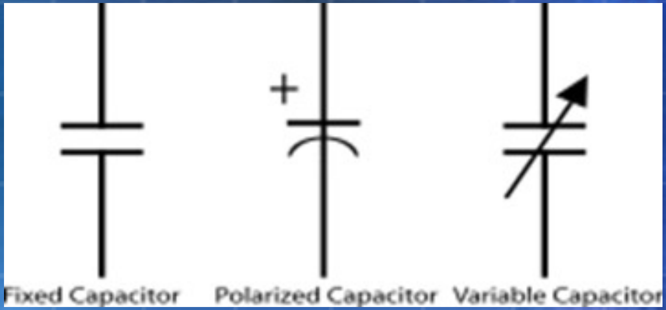


A component-level diagram of the common 741 op-amp. Dotted lines outline: current mirrors; differential amplifier; class A gain stage; voltage level shifter; output stage.

https://en.wikipedia.org/wiki/Operational_amplifier

Capacitors

- A capacitor is a passive two-terminal electrical component that stores potential energy in an electric field
- Most capacitors contain at least two electrical conductors often in the form of metallic plates or surfaces separated by a dielectric medium (glass, ceramic, plastic, paper, mica, etc.). A conductor may be a foil, thin film, sintered bead of metal, or an electrolyte.
- Unit of capacitance is a Farad (F). Most capacitors have small values like µF, pF, etc.



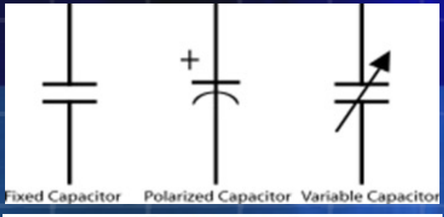
Charge equals Capacitance times Potential

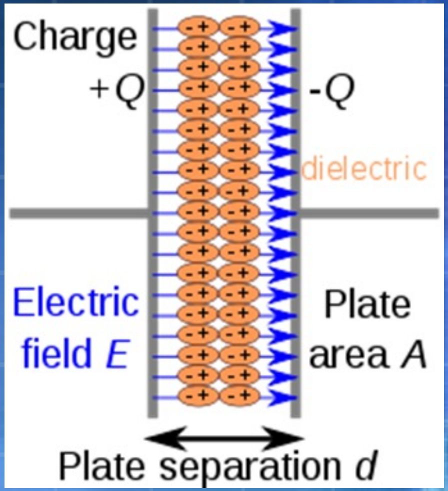
- Q = C V

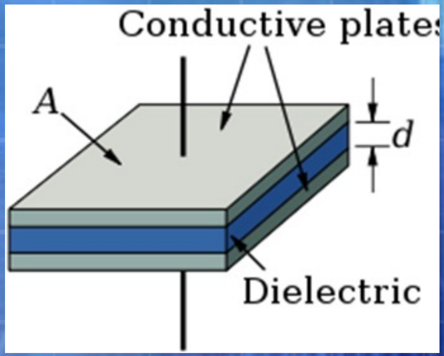
https://en.wikipedia.org/wiki/Capacitor
https://courses.physics.illinois.edu/phys102/sp2013/lectures/lecture7.pdf

Capacitors

- A capacitor consists of two conductors separated by a non-conductive region where charge builds up on both sides
- When charging the current flows freely at first so it appears to be a short (with zero voltage)
- When fully charged the current is completely stopped so it appears to be an open (with maximum voltage).
- A capacitance of one Farad (F) means that one Coulomb of charge on each conductor causes a voltage of one Volt (V) across the device
  - Q = C V





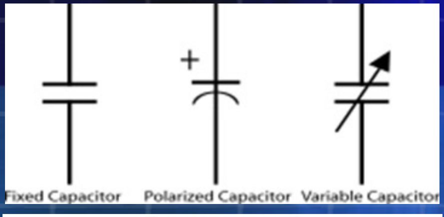


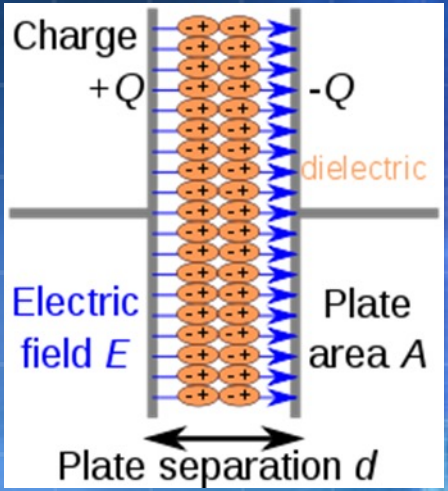
https://en.wikipedia.org/wiki/Capacitor
https://courses.physics.illinois.edu/phys102/sp2013/lectures/lecture7.pdf

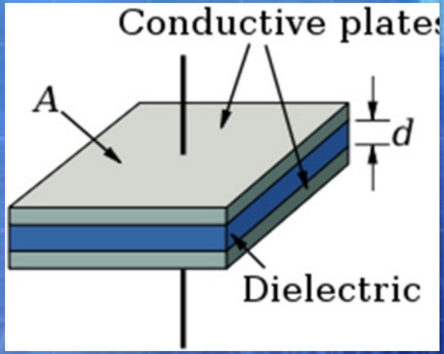
Capacitors

(Parallel Plate Model)

- The simplest model of a capacitor consists of two parallel plates with a thin dielectric in between.
  - The dielectric is much thinner than the dimensions of the plates
  - The dielectric permittivity (ε) of the material determines how much capacitance can be held
- $C = \varepsilon A / d$
- Energy stored in a capacitor is $E = \frac{1}{2} CV^2$
- Free space/vacuum has a permittivity of $\varepsilon_o = 8.854 \times 10^{-12}$ F/m, all other materials are higher





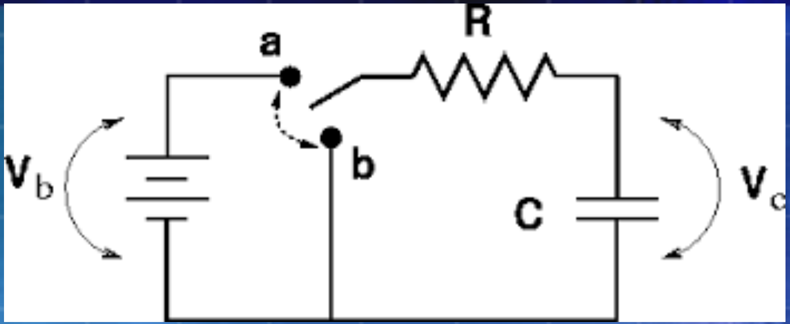


https://en.wikipedia.org/wiki/Capacitor
https://courses.physics.illinois.edu/phys102/sp2013/lectures/lecture7.pdf

RC Circuits

(Division C Only)

- Most RC problems involve a Resistor (R) and a Capacitor (C), which is charged by a battery and then discharged for the start
  - Usually with a switch that is set to charge or discharge the capacitor
  - The time constant, $\tau = RC$, is in unit of seconds
  - τ is the time it takes to charge a capacitor to about 63% of max value
  - τ is the time it takes to discharge a capacitor to about 37% of its original value
- Charge and voltage don't change instantaneously so they are the same right before and right after the switch
- Current starts as a short when charging and goes to zero long term.
- Current starts at maximum value (i.e. if it was a short during charging) when discharging and goes to zero long term



Common problem start conditions

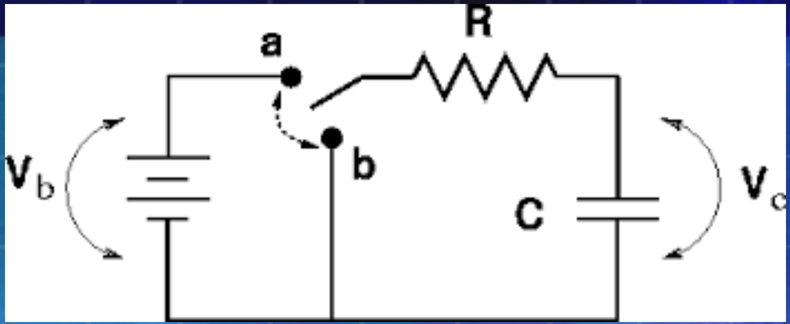
- Switch is set to b for a very long time
  - This discharges the capacitor so $V_c = 0V$
- Switch is set to a for a very long time
  - This charges the capacitor so $V_c = V_b$

https://en.wikipedia.org/wiki/Capacitor
https://courses.physics.illinois.edu/phys102/sp2013/lectures/lecture7.pdf

RC Circuits

(transient charging)

- Most RC problems involve a Resistor (R) and a Capacitor (C), which is charged by a battery and then discharged
  - Usually with a switch that is set to charge or discharge the capacitor
  - The time constant, $\tau = RC$
- If starting discharged, $V_c(t=0) = 0V$
  - If switch is turned to a (charging position) at t=0, the capacitor begins to charge
  - The charge as a function of time increases $Q(t) = V_{max}(1-e^{-t/RC})$



Common problem solution method

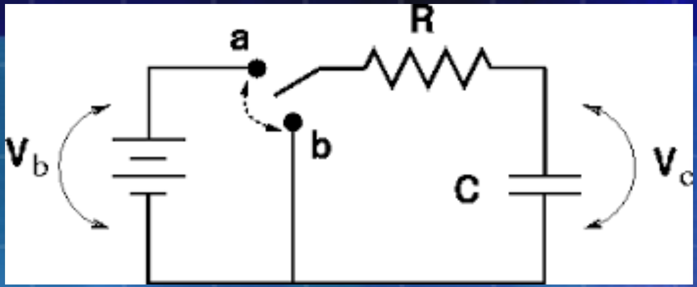
- Find start condition (usually either fully discharged or charged)
- Determine the impact of the change at t=0 (charging or discharging)
- Combine Capacitors if needed as normally
- Solve for the equivalent R as seen by the Capacitor during charging
  - All voltage sources are treated as shorts and all current sources are treated as open
  - Combine normally
  - Determine what the maximum charged voltage (V_{max}) would be in the charging position
- Calculate $\tau = RC$
- Using V_{max} and $\tau = RC$ you can resolve current and voltage or charge as a function of time

https://en.wikipedia.org/wiki/Capacitor
https://courses.physics.illinois.edu/phys102/sp2013/lectures/lecture7.pdf

RC Circuits

(transient charging cont)

- If starting discharged, $V_c(t=0) = 0V$
  - If switch is turned to a (charging position) at t=0, the capacitor begins to charge, usually from zero
  - $\tau = RC$
  - $V_{max} = V_b$ (since eventually the current through R goes to zero and so the voltage at $V_b = V_c$
  - The charge as a function of time increases $Q(t) = (V_{max}/C)(1-e^{-t/RC})$
  - $V(t) = V_{max}(1-e^{-t/RC})$
  - $I(t) = (V_{max}/R)e^{-t/RC}$



Common problem solution method

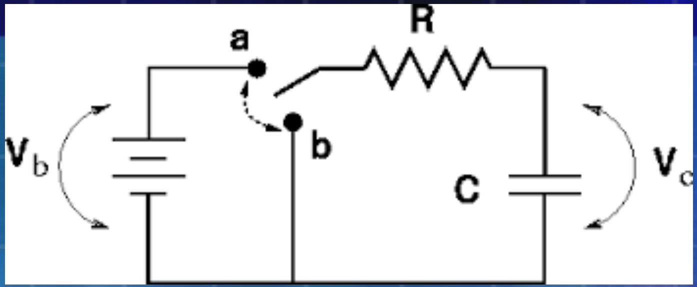
- Find start condition (usually either fully discharged or charged)
- Determine the impact of the change at t=0 (charging or discharging)
- Combine Capacitors if needed as normally
- Solve for the equivalent R as seen by the Capacitor during charging
  - All voltage sources are treated as shorts and all current sources are treated as open
  - Combine normally
  - Determine what the maximum charged voltage (V_{max}) would be in the charging position
- Calculate $\tau = RC$
- Using V_{max} and $\tau = RC$ you can resolve current and voltage or charge as a function of time
- Double check the voltage and current at $t = \infty$

https://en.wikipedia.org/wiki/Capacitor
https://courses.physics.illinois.edu/phys102/sp2013/lectures/lecture7.pdf

RC Circuits

(transient discharging cont)

- If starting discharged, $V_c(t=0) = V_b$
  - If switch is turned to a (discharging position) at t=0, the capacitor begins to discharge, from V_{max} τ = RC
  - $V_{max} = V_b$ (since eventually the current through R goes to zero and so the voltage at $V_b = V_c$
  - The charge as a function of time decreases $Q(t) = (V_{max}/C)(e^{-t/RC})$
  - $V(t) = V_{max}(e^{-t/RC})$
  - $I(t) = (V_{max}/R)e^{-t/RC}$



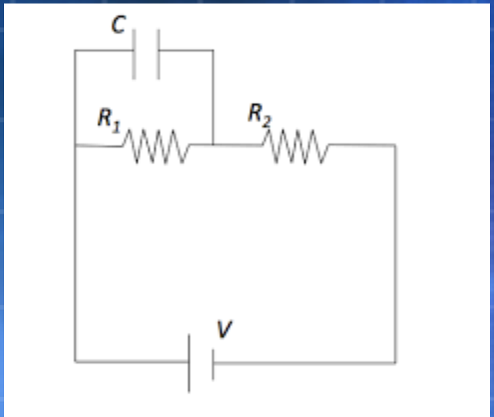
Common problem solution method

- Find start condition (usually either fully discharged or charged)
- Determine the impact of the change at t=0 (charging or discharging)
- Combine Capacitors if needed as normally
- Solve for the equivalent R as seen by the Capacitor during charging
  - All voltage sources are treated as shorts and all current sources are treated as open
  - Combine normally
  - Determine what the maximum charged voltage (V_{max}) would be in the charging position
- Calculate τ = RC
- Using V_{max} and τ = RC you can resolve current and voltage or charge as a function of time
- Double check the voltage and current at t = ∞

https://en.wikipedia.org/wiki/Capacitor
https://courses.physics.illinois.edu/phys102/sp2013/lectures/lecture7.pdf

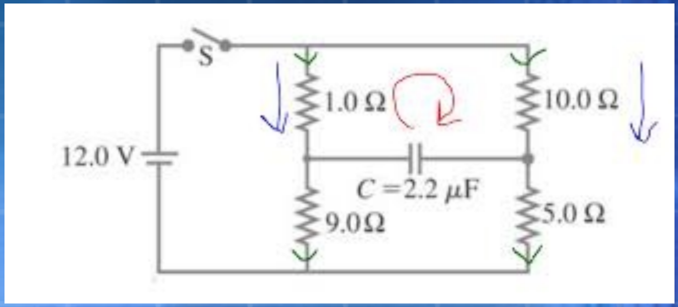
Practice

- What is the time constant for charging the system to the right, if $R_1 = R_2 = 1k\Omega$ and $C = 10\ mF$
- What is the fully charged value of C if V = 12V
- If after fully charged, the battery is removed (leaving an open), how long to discharge 37% of the charge?
- If after fully charged, the battery is removed (leaving a short), how long to discharge 37% of the charge?
- If fully discharged and the battery is added at t=0, what is the formula for I_{R2}



Practice

- What is maximum voltage for V_c if the switch has been closed for a really long time
- At t = 0, the switch is then opened
  - What is the time constant for discharging
  - What is the formula for $V_c(t)$



https://physicsstackexchange.com

Homework

- Update your binder to get it competition ready
- Complete the circuit problems from the Homework Generator
  - Level 16 Operational Amplifiers
  - Level 17 RC Circuits
- Complete the in class practice problems using your own methods, showing all work. Make sure that your work can be followed by others.
- Design an RC circuit with a 10 pF capacitor that has a maximum voltage of 10V and a time constant of 0.3 msec
- Determine the equations for current, charge, and voltage as a function of time for the capacitor in that design