Electrical

Engineering

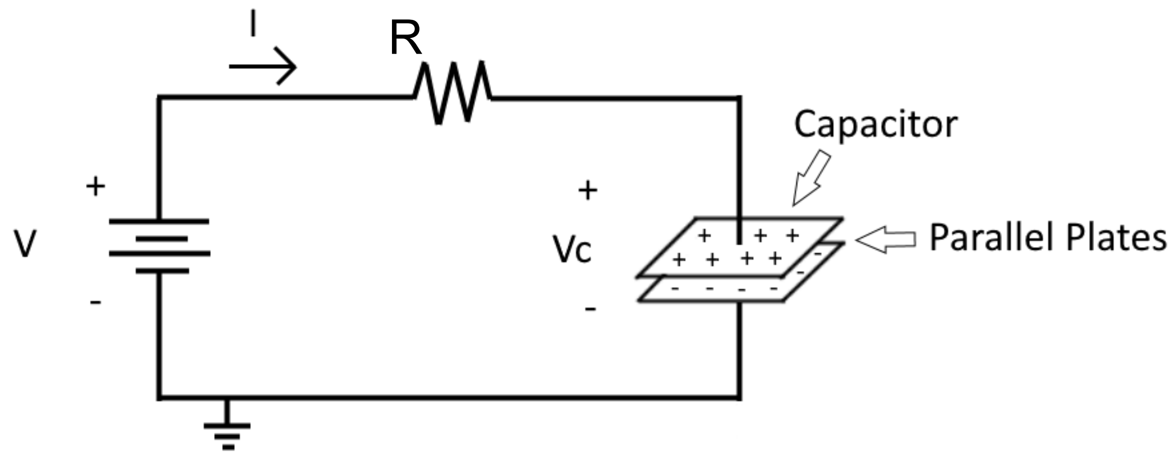
Technology

Capacitors and Charge Intro

Fall 2018

Chapter 10 - Capacitors

- Passive Components
  - Resistors – dissipate energy
  - Capacitors & Inductors – store energy (ideally)
- Capacitors
  - Store energy in an electric field



- Energy Storage Action:
  - Parallel metal plates – dielectric material in-between, acts as an insulator
  - I flows to 'fill' parallel plates, initially only limited by R
  - V_C starts at 0 V and increases until $V_C = V$
  - I drops to 0 A once $V_C = V$ (no more charge flow)
  - Energy is stored in C

Example:

What is the capacitance of a parallel plate capacitor if 1000 μC of charge are deposited on its plates when 10 V are applied across the plates? When 50 V are applied?

$$C = \frac{Q}{V} = \frac{1000\ \mu C}{10\ V} = 100\ \mu F$$

$$C = \frac{Q}{V} = \frac{1000\ \mu C}{50\ V} = 20\ \mu F$$

Example:
What is the capacitance of a parallel plate capacitor if the area of each plate is 0.050 m^2 and the distance between the plates is 1.5 mm? The dielectric is air.

$$C = \epsilon_o \times \epsilon_r \times \frac{A}{d}\ (F)$$

$\epsilon_o = 8.85 \times 10^{-12}$ F/m (Permittivity of a vacuum)

$\epsilon_r = 1.006$ (Table 10.1, relative permittivity of air)
$A = 0.050\ m^2$
$d = 1.5 \times 10^{-3}\ m$

$$C = (8.85 \times 10^{-12}\ F/m)\ (1.006) \times \frac{0.050\ m^2}{1.5 \times 10{-}3\ m}$$
$$= 295.2\ pF$$

Dielectric Strength

- Breakdown Voltage
  - The voltage required per unit length to establish conduction in a dielectric

Table 10.2 (Partial)	
Air	75 V/Mil
Teflon	1500 V/Mil
Mica	5000 V/Mil
Porcelain	200 V/Mil

Example:
Find the breakdown voltage of a capacitor with d = 100 μm and a porcelain dielectric.

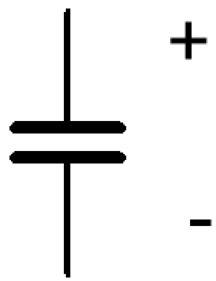
Example:
Find the breakdown voltage of a capacitor with d = 100 µm and a porcelain dielectric.

Porcelain : 200 V/Mil

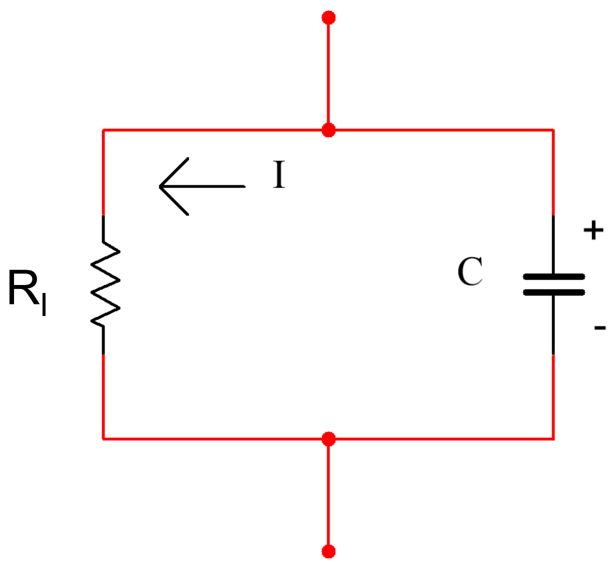
$$d = 100\ \mu m \times \frac{1\ mm}{1000\ \mu m} \times \frac{1\ inch}{25.4\ mm} \times \frac{1000\ Mils}{1\ inch} = 3.94\ Mils$$

$$V_{max} = \frac{200\ V}{Mil} \times 3.94\ Mils = 788\ V$$ <- Capacitors have voltage ratings

Leakage Current

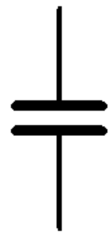


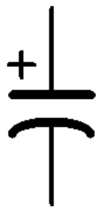
- Ideal Capacitor
  - Charge stored forever if left open circuit
- Leakage Resistance - R_l
  - Capacitor will self discharge through R_l
  - R_l generally very large (MΩ or greater)
  - Lower for electrolytic capacitors



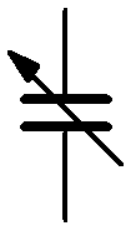
Types of Capacitors

- Fixed





- Variable



Types of Capacitors

- Fixed
  - By dielectric type:
    - Mica:
      - Low leakage
      - R_l ~1000 MΩ
      - Stable over temperature
      - 100 V or more
      - 1 pF to 0.2 μF
    - Ceramic:
      - Similar to mica, but generally not as stable over temperature
      - Up to 5 kV
      - C up to 2 μF or more
    - Electrolytic:
      - Low R_l
      - 1 μF to several thousand μFs
    - Tantalum
    - Polyester Film

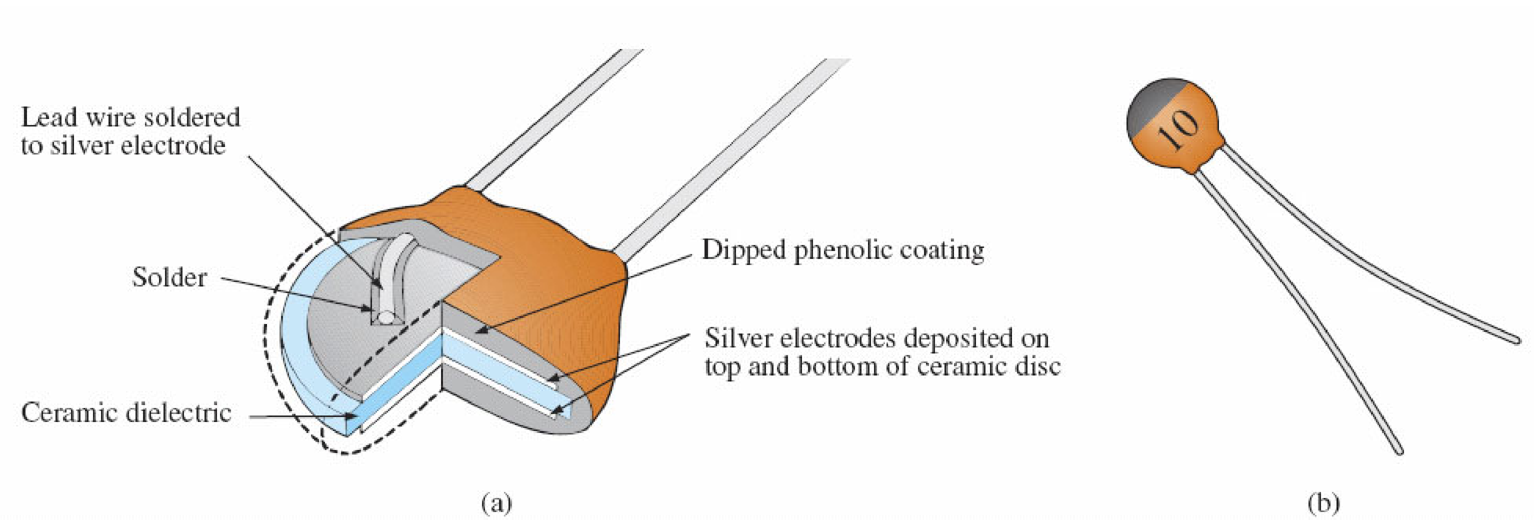


FIG. 10.16 *Ceramic (disc) capacitor: (a) construction; (b) appearance.*

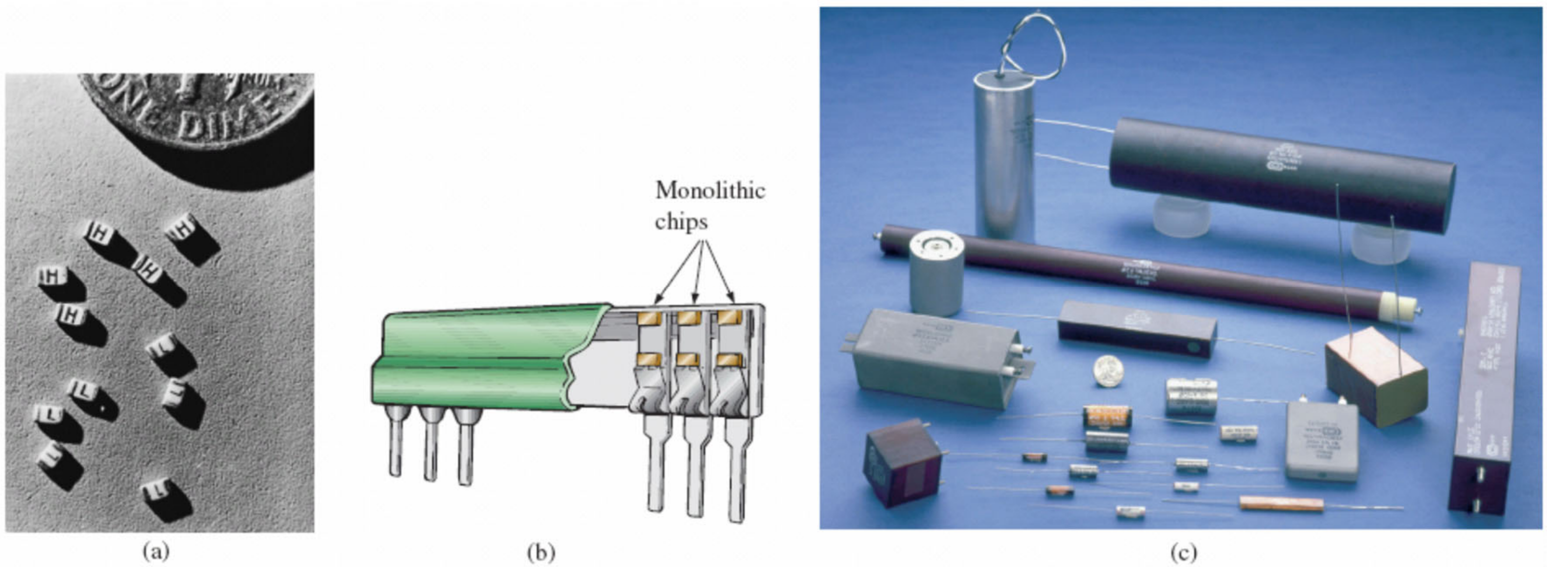
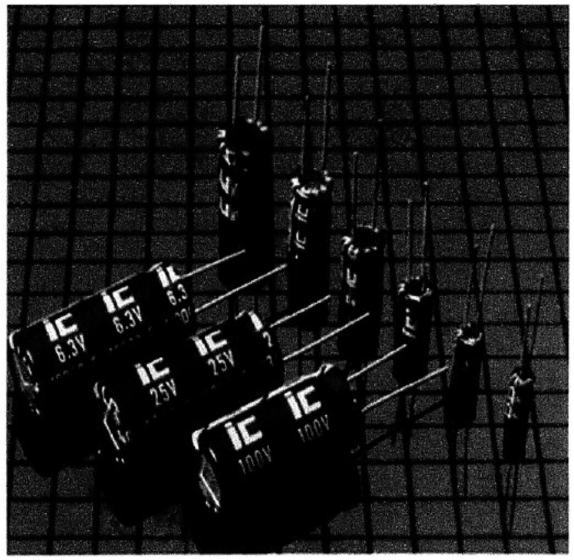
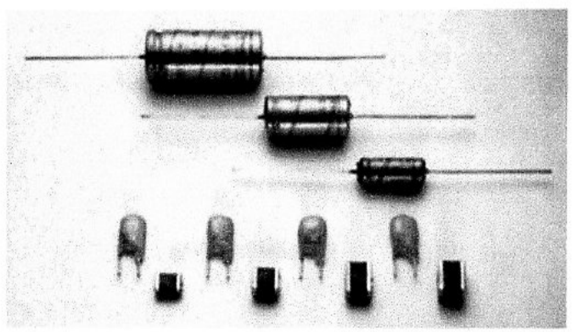


FIG. 10.17 *Mica capacitors: (a) and (b) surface-mount monolithic chips; (c) high-voltage/temperature mica paper capacitors.* [(a) and (b) courtesy of Vishay Intertechnology, Inc.; (c) courtesy of Custom Electronics, Inc.]

FIGURE 10.15 Electrolytic capacitors: (a) Radial lead with extended endurance rating of 2000 h at 85°C. Capacitance range: 0.1-15,000 μF with a voltage range of 6.3 to 250 WV dc (Courtesy of Illinois Capacitor, Inc.). (b) Solid aluminum electrolytic capacitors available in axial, resin-dipped, and surface-mount configurations to withstand harsh environmental conditions (Courtesy of Philips Components, Inc.).



(a)



(b)

Robert L. Boylestad
Introductory Circuit Analysis, 10ed.

FIGURE 10.22 Summary of capacitive elements.

∝ ⇒ μ (MISPRINT)

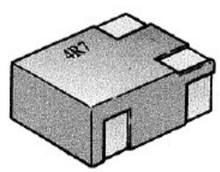
Type: Miniature Axial Electrolytic
Typical Values: 0.1 ∝F to 15,000 ∝F
Typical Voltage Range: 5 V to 450 V
Capacitor tolerance: ±20%
Applications: Polarized, used in DC power supplies, bypass filters, DC blocking.

Type: Miniature Radial Electrolyte
Typical Values: 0.1 ∝F to 15,000 ∝F
Typical Voltage Range: 5 V to 450 V
Capacitor tolerance: ±20%
Applications: Polarized, used in DC power supplies, bypass filters, DC blocking.

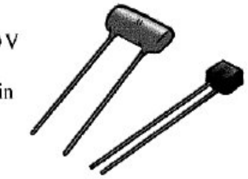
Type: Ceramic Disc
Typical Values: 10 pF to 0.047 ∝F
Typical Voltage Range: 100 V to 6 kV
Capacitor tolerance: ±5%, ±10%
Applications: Non-polarized, NPO type, stable for a wide range of temperatures. Used in oscillators, noise filters, circuit coupling, tank circuits.

Type: Dipped Tantalum (solid and wet)
Typical Values: 0.047 ∝F to 470 ∝F
Typical Voltage Range: 6.3 V to 50 V
Capacitor tolerance: ±10%, ±20%
Applications: Polarized, low leakage current, used in power supplies, high frequency noise filters, bypass filter.

Type: Surface Mount Type (SMT)
Typical Values: 10 pF to 10 ∝F
Typical Voltage Range: 6.3 V to 16 V
Capacitor tolerance: ±10%
Applications: Polarized and non-polarized, used in all types of circuits, requires a minimum amount of PC board real estate.



Type: Silver Mica
Typical Value: 10 pF to 0.001 ∝F
Typical Voltage Range: 50 V to 500 V
Capacitor tolerance: ±5%
Applications: Non-polarized, used in oscillators, in circuits that require a stable component over a range of temperatures and voltages.

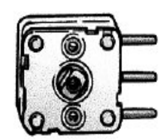


Type: Mylar Paper
Typical Value: 0.001 ∝F to 0.68 ∝F
Typical Voltage Range: 50 V to 600 V
Capacitor tolerance: ±22%
Applications: Non-polarized, used in all types of circuits, moisture resistant.

Type: AC/DC Motor Run
Typical Value: 0.25 ∝F to 1200 ∝F
Typical Voltage Range: 240 V to 660 V
Capacitor tolerance: ±10%
Applications: Non-polarized, used in motor run-start, high-intensity lighting supplies, AC noise filtering.

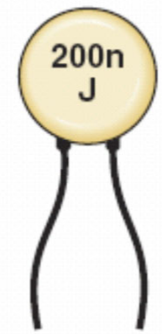
Type: Trimmer Variable
Typical Value: 1.5 pF to 600 pF
Typical Voltage Range: 5 V to 100 V
Capacitor tolerance: ±10%
Applications: Non-polarized, used in oscillators, tuning circuits, AC filters.

Type: Tuning variable
Typical Value: 10 pF to 600 pF
Typical Voltage Range: 5 V to 100 V
Capacitor tolerance: ±10%
Applications: Non-polarized, used in oscillators, radio tuning circuit.



(a)

In Class Problem



(b)

In Class Problem

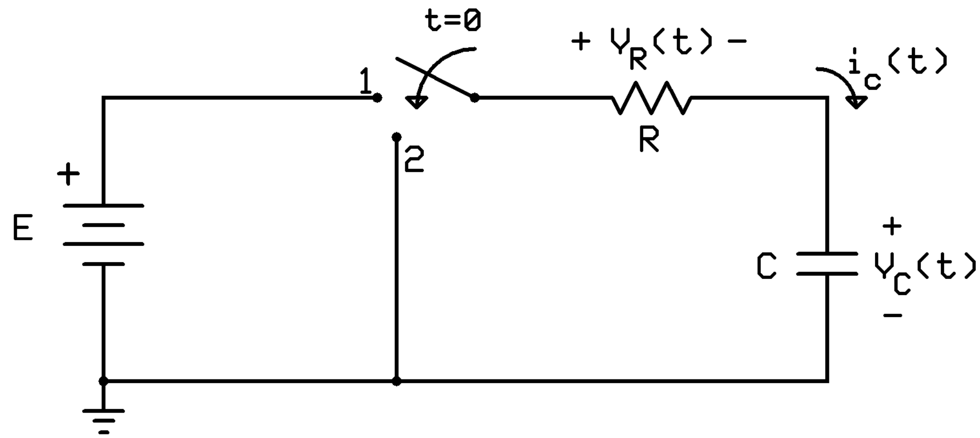
(c)

In Class Problem

(d)

In Class Problem

Capacitor Transient Analysis (charge phase, pos. 1)



No initial charge

t<0 : Switch is open -> $i_c(t) = 0$, $V_c(t) = 0$

t=0$^+$: Switch just closed (pos. 1) -> $i_c(t) = i_{cmax}$, since $V_c(0^+) = 0V$

t>0 : $V_c(t)$ increases, $i_c(t)$ decreases
Recall : $Q = CV$ -> $V = Q/C$ $\therefore Q\uparrow \propto V\uparrow$

t>>0 : $V_c(t) = E$ -> $i_c(t) = 0$ (Capacitor is effectively an open-circuit), Capacitor is fully charged

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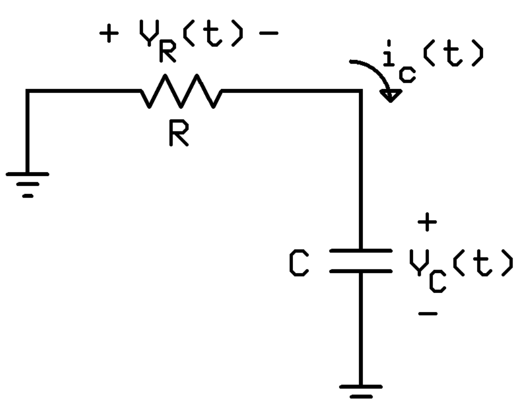
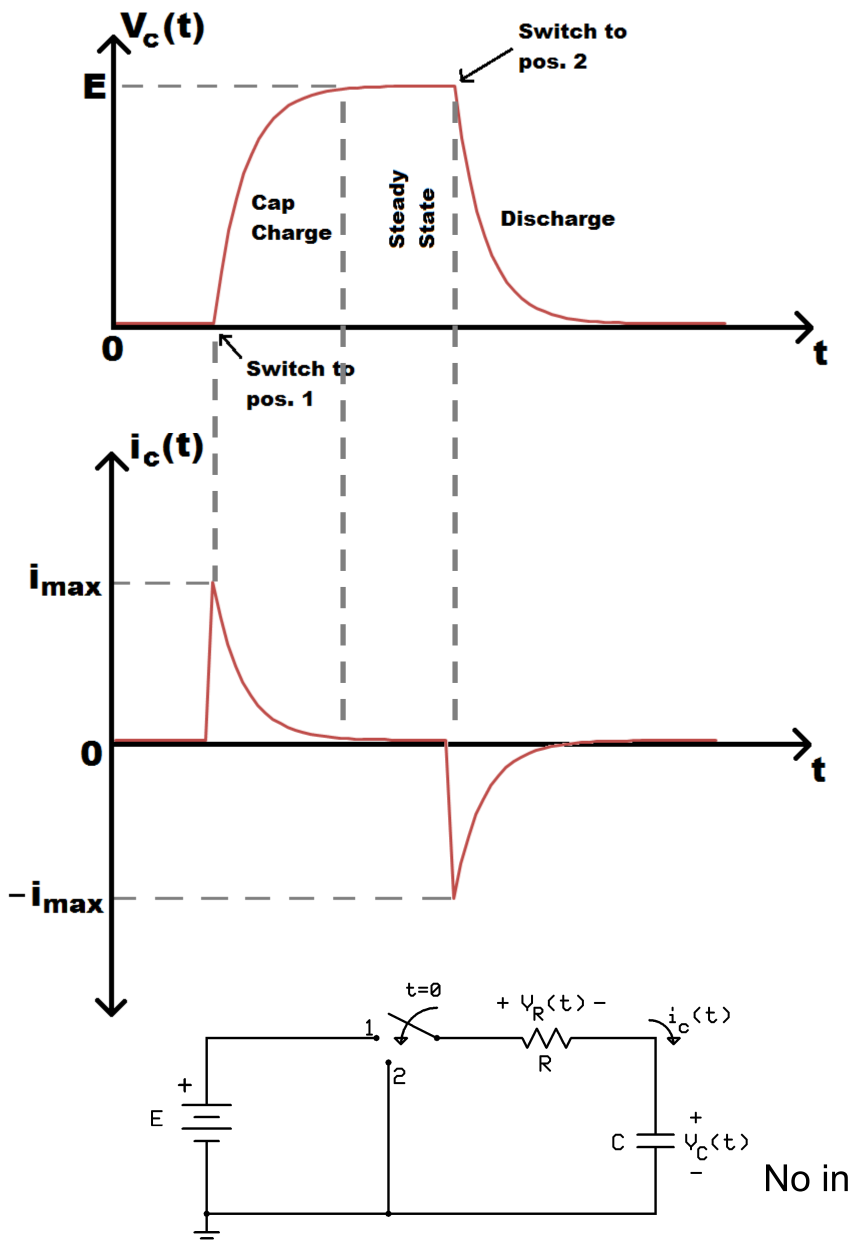


Switch from pos. 1 to pos. 2 (discharge phase):
- Capacitor will discharge, opposite to defined direction of $i_c(t)$
- Eventually $V_c(t) = 0$, capacitor is fully discharged



No initial charge

Equations for the <u>charge phase</u>:

$$i_c(t) = \frac{E}{R} * e^{-t/RC}$$

$$i_c(t) = \frac{E}{R} * e^{\frac{-t}{\tau}}$$

$$V_r(t) = i_c(t) * R$$

$$V_r(t) = E * e^{\frac{-t}{\tau}}$$

Unit check for tau:

$$\tau = RC$$

$$RC = \left(\frac{V}{I}\right)\left(\frac{Q}{V}\right)$$

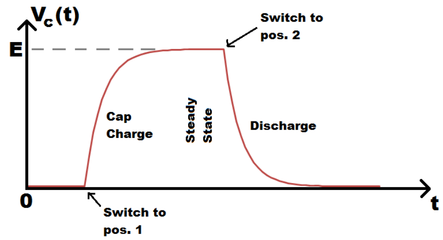
$$RC = \left(\frac{V}{\frac{Q}{t}}\right)\left(\frac{Q}{V}\right)$$

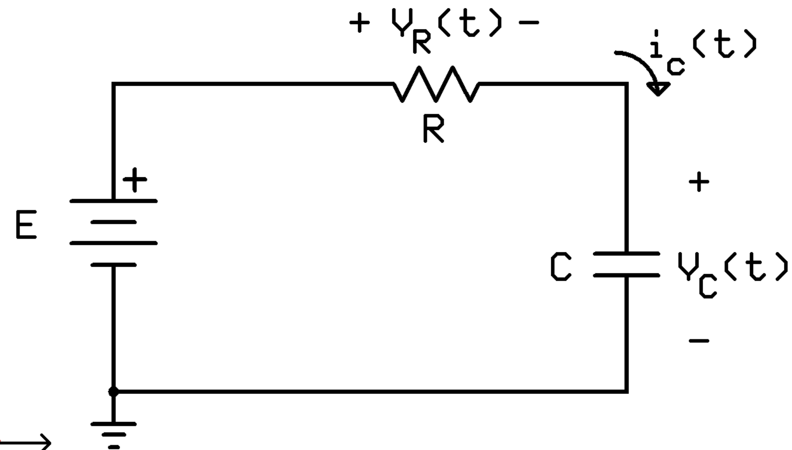
$$RC = \left(V * \frac{t}{Q}\right)\left(\frac{Q}{V}\right)$$ = t, seconds

Equations for the **charge phase**:

$$i_c(t) = \frac{E}{R} * e^{\frac{-t}{\tau}}$$

$$V_r(t) = E * e^{\frac{-t}{\tau}}$$





KVL is still true!

$$E - V_R(t) - V_C(t) = 0$$

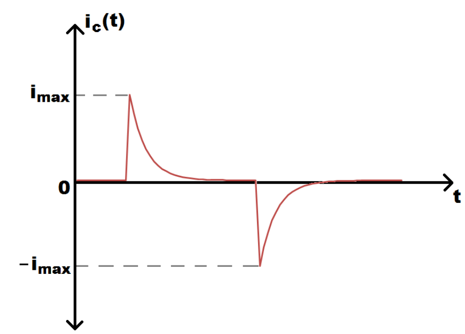
$$V_C(t) = E - V_R(t)$$

$$V_C(t) = E - E * e^{\frac{-t}{\tau}}$$

$$V_C(t) = E\left(1 - e^{\frac{-t}{\tau}}\right)$$

Looking at $i_c(t) = \frac{E}{R} * e^{\frac{-t}{\tau}}$

t	$i_c(t)$		
0	$\frac{E}{R}$	← Initial value	
$RC = \tau$	$\frac{E}{R}\left(e^{-1}\right)$	$= 0.368\left(\frac{E}{R}\right)$	36.8% of E/R
$2RC = 2\tau$	$\frac{E}{R}\left(e^{-2}\right)$	$= 0.135\left(\frac{E}{R}\right)$	13.5% of E/R
$3RC = 3\tau$	$\frac{E}{R}\left(e^{-3}\right)$	$= 0.05\left(\frac{E}{R}\right)$	5% of E/R
$4RC = 4\tau$	$\frac{E}{R}\left(e^{-4}\right)$	$= 0.018\left(\frac{E}{R}\right)$	1.8% of E/R
$5RC = 5\tau$	$\frac{E}{R}\left(e^{-5}\right)$	$= 0.0067\left(\frac{E}{R}\right)$	0.67% of E/R



Less than 1% of max (initial) current. Considered "fully charged".