ETE 2200

Enhanced Guided Notes: Set 9

Capacitance

Topics:

- **A. The Electric Field**
- **B. Capacitance**
- **C. Capacitors**
- **D. Types**
- **E. Transients in Capacitive Networks: Charging Phase**
- **F. Transients in Capacitive Networks: Discharge Phase**
- **G. Initial Conditions**
- **H. Instantaneous Values**
- **I. Capacitors in Series and Parallel**
- **J. Stored Energy in Capacitors**

A. The Electric Field

- Is represented with electric flux lines indicating the strength of the electric field at any point around the charged body
- Denser lines of flux = ________________ energy field
- Symbol is ψ (□)
- Flux per unit area (flux density)

$$D = \frac{\Psi}{A}$$

Ψ = electric flux

D = flux per unit area

A = area

Ψ □ Q ★What does this relationship indicate?

Electric Field Strength

$$\mathcal{E} = \frac{F}{Q}$$

F = Force (N)

Q = charge (c)

□ (epsilon) = electric field strength (N/c)

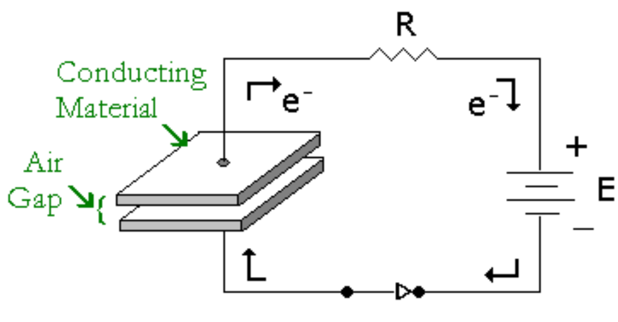
Recall: Coulomb's Law and substitute it into the electric field strength equation for F.

So electric field strength is directly related to the size of the charge _________________.

Remember: electric flux lines always flow from + to – charged body and always enters perpendicular to a body's surface while never intersecting.

Draw the flux lines between the two sets of particles

B. Capacitance



Draw the charge accumulation on the plates for the closed circuit.

What will be the maximum potential (V) that will be seen across the plates?

1. Capacitance is a ___________ of a capacitors ability to store

   charge on its plates, also called ____________ ____________

   - Charge never flows through the air space between plates, only back through the circuit

2. A higher capacitance for a given capacitor with the same

   - Applied voltage means a _________ amount of charge can be stored on the plates

3. Capacitance is measured in Farad (F)

   - What is the capacitance of a capacitor allowing 1C charge to be deposited on plates with a potential difference of 1V across the plates? 1C charge = how many e^-?

Capacitance

$$C = \frac{Q}{V}$$

C = Farads (F)
Q = coulombs (C)
V = volts (V)

Electric Field Strength

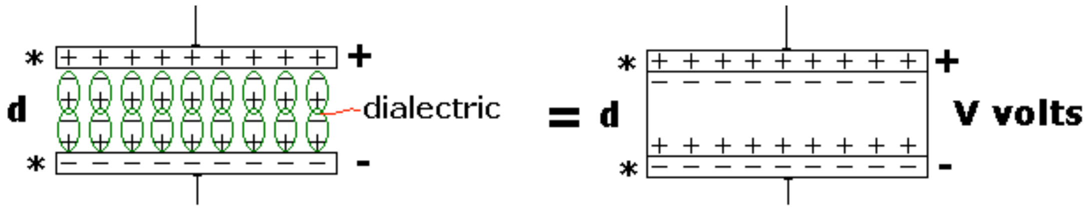
$$\varepsilon = \frac{V}{d}$$

□ = volts/m (V/m)
V = Volts (V)
d = meters (m)

What type of material do we want to use to isolate the plates?

This separating material is called a **dialectric**!

The dialectric __________ e- flow between plates but does allow the realignment of its positive and negative components (+ and -)



★ Why do all the middle charges get ignored in the second sketch?

Different dialectric materials will require more charges on the

plate to not ____________________ the electric field strength between the plates.

★ Why can the electric field strength not be reduced?

_______________ _________________ is a measure of the ease of permittance for the establishment of an electric field in the material. It's a comparison to air!

See pg. 403 table 10.1

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$$

$\square_0$ = permittivity of air

$\square_r$ = relative permittivity of material (dialectric constant)

$\square$ = permittivity of material

$\square_r$= is dimensionless and = 1.006 for air

$\square_0$ = farads/meter at 8.85×10^{-12} F/m for air

★ What does dimensionless mean, and why is $\square_r$ dimensionless?

★ T/F There is no potential that can break down a dialectric and allow current to flow through it. Give a common example to prove your answer.

Breakdown Voltage

- Voltage per unit length that will breakdown dialectric
- Indicates "dialectric strength"
  p. 403 Table 10.2

Maximum working voltage

Definition:

★ What is the difference between breakdown and maximum working voltages?

✵ Examples:

225.6×10^{20} electrons are deposited on the negative plate of a capacitor by an applied voltage of 100V. What is the capacitance of the capacitor?

50 Coulombs of charge exist with an electric field strength of 40N. What is the associated force?

A 40 Volt potential difference is measured across two plates 1mm apart. What is the electric field strength associated with the two plates?

C. Capacitors

What would be the effect of A) Larger plates

B) Smaller Separating distances

C) Higher permittivity

Let’s define an equation with these parameters

C=

Substitute permittivity E_Q into this and we get…?

Or with the substitution of the known air permittivity value

Capacitance of capacitor with specific dialectric related to capacitor with air as dialectric

$C = \square_r C_0$

$\square_r$= relative permitivity

C_0= capacitance with air as dialectric

C = capacitance of new dialectric

✵ Examples:

A capacitor measuring 3 inches by 2 inches for both of its plates with an 1/8 inch air gap is tested. What is its capacitance, strength of its electric field if 24 volts is applied, and the associated charge on each plate?

D. Types of Capacitors

Fixed In general for same type of construction and dialectric

The ___________ the required capacitance, the larger the

____________ of the capacitor

★ increase size is due to which aspect of the capacitance formula?

Electrolytic capacitors
Usually have polarity markings
Working voltages limited
0.1 μF to 10 μF

Film, _____________, foil, etc. capacitors
Rolling or stacked process ↑ surface area
100 pF to 10 μF

Ceramic capacitors
High working voltages
_______ pF to 0.047 μF

Mica capacitors
________ pF to several micro farads
High voltage

Dipped capacitor
0.1 μF to _______ μF
6 to 50 V
Must hook up correctly

Oil capacitor
Industrial applications
0.001 μF + 10,000 μF
Up to 150 kV

Variable Capacitor

Can change surface area interaction in plates that mesh like fingers

Leakage Current

All capacitors leak some e- through dialectric

Usually small enough to ignore

Become a problem when capacitor sits in charged state for a long time

Temperature Effects: PPM

★ Do you think temperature will interfere with capacitance?

Capacitor Labeling

Size usually designates pF or μF

______ = K   ______ = J   1% = F   20% = M

2# means size in pF or μF depending on physical size

3#'s + lowercase letter = size and multiplier and then tolerance

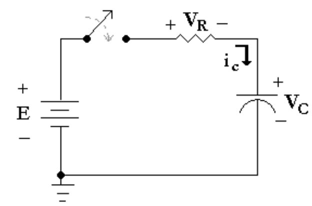
3#'s + uppercase letter = size and multiplier and tolerance

E. Transients in Capacitive Networks: Charging Phase

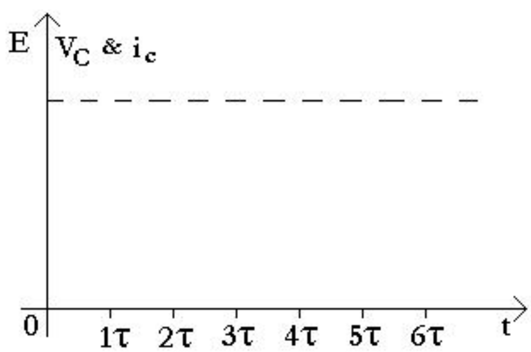
Charge placement on capacitor plates is not instantaneous

★ What could affect the charging time?

Define "Transient period"



Draw a plot of the voltage across a capacitor vs. time



$V_C = E\,(1 - e^{-t/\tau})$ charging

$\tau = RC$

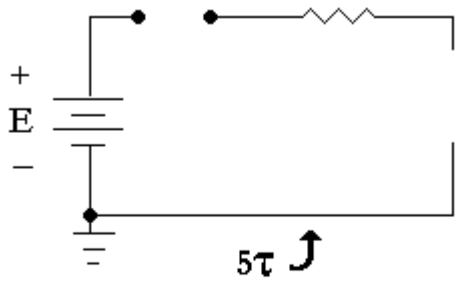
★ What is the voltage after 5 time constants?

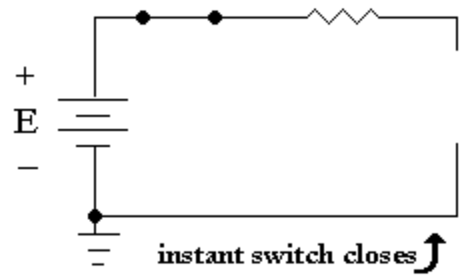
★ What is the current in the circuit after 5 time constants?

★ Plot the current

$$i_c = \frac{E}{R} e^{-t/\tau}$$

★ A circuit drawn to represent conditions after 5 time constants would look like what? Draw it below! Draw the circuit the instant the switch closes.





The time constant will always have some value ∴ the voltage across a capacitor cannot change instantly

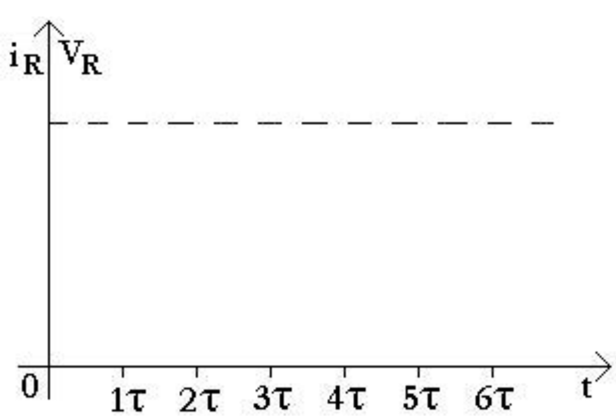
A large τ means the capacitor will need a larger amount of ____ to reach its applied voltage value.

Resistor is in _______ with capacitor so using Ohm's Law

$V_r = i_R R = i_c R$ so $V_r = \left(\frac{E}{R} e^{-t/\tau}\right) R$

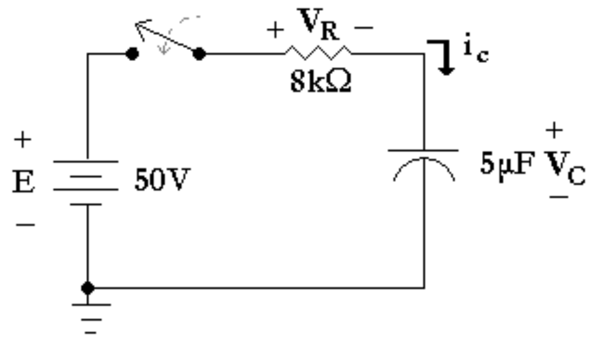
∴ $\boxed{V_R = Ee^{-t/\tau}}$ charging

★ Draw the plot of resistor current versus time for the capacitive circuit we've talked about. What about the voltage across the resistor?



❋ Examples:
(Use back if necessary)

For the given circuit

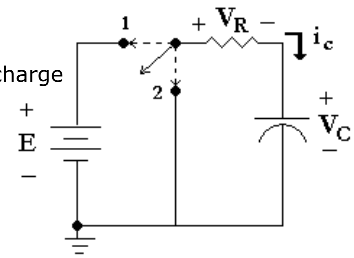


1) Find the mathematical expression for the expression of the transient behavior of V_C, i_C, and V_R if the switch is closed at t=0 seconds.
2) Plot the waveform of V_C vs. network time constant.
3) Plot the waveform of V_C vs. time.
4) Plot the waveform of i_C and V_R vs. network time constant.
5) What is the value of V_C at t=30 ms.
6) How long until we can assume charging phase is complete?
7) How much charge will there be on the plate?
8) If the capacitor has a leakage resistance of 10,000 MΩ

F. Transients in Capacitive Networks: Discharge Phase

Voltage across capacitor $\boxed{V_C = Ee^{-t/\tau}}_{\text{discharge}}$ $\tau = RC_{discharge}$

Voltage across capacitor $\boxed{i_c = \frac{E}{R} e^{-t/\tau}}_{\text{discharge}}$



Voltage across resistor

Since $V_R = V_C$ this equation is the same as for charging

$$\boxed{V_R = Ee^{-t/\tau}}_{\text{discharge}}$$

★ How long do you think it will take for complete discharge?

★ Redraw the circuit traveled by the current when the switch is at position 2?

★ Draw or plot V_C, i_C, V_R during discharge

★ If τ is smaller, what will that do to the V_C, i_C, and V_R response for the charging cycle?

★ How do we alter this τ value?

G. Initial Conditions

Conditions: capacitor was not fully discharged before switch is thrown.

After 5τ we are at "steady state conditions"

$$\mathbf{V_C = V_f + (V_I - V_f)\, e^{-t/\tau}}$$

τ = time constant
V_I = initial volt
V_f = final volt
V_C = volt at capacitor
T = time of interest

★ Can this equation be used for charging and discharging phase?

H. Instantaneous Values

Use calculators now. Fig 10.29 accuracy suspect beyond 0.1.

To find time

$$t = \tau(\log_e)\frac{(V_i - V_f)}{(V_c - V_f)}$$

$$t = \tau \log_e \frac{V_i}{V_c}$$

$$t = \log_e \frac{I_i}{I_c}$$

You can simplify (Thévenin equivalent) a circuit for network external to capacitive element

I. Capacitors in Series and Parallel

Series $\quad Q_T + Q_1 = Q_2 = Q_3$ $\quad$ Charge is same on each capacitor

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Total capacitance of 2 capacitors

$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

Voltage across capacitor

$$V_1 = \left(\frac{\frac{1}{C_1}}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}} \right) E$$

Parallel

$$Q_T = Q_1 + Q_2 + Q_3$$

$$\therefore \quad C_T = C_1 + C_2 + C_3$$

J. Stored Energy in Capacitors

$$W_C = ½ CV^2$$

V = steady state voltage
C = the capacitance

or

$$W_C = \frac{Q^2}{2C}$$

★ Prove the second equation from the first.