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Unit - I
1.8 Capacitors

Wireless power transmission

→ Short distance → long ~~st~~ distance

Dr.Santhosh.T.K.

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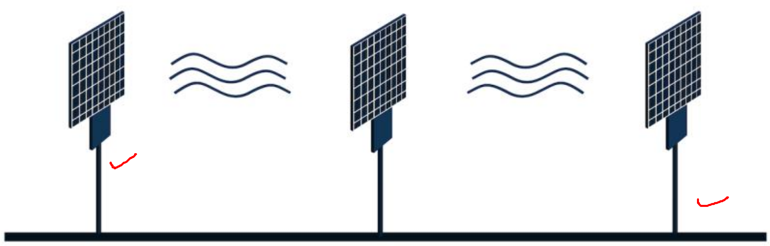
Wireless Power Transmission



PowerCo →

https://emrod.energy/wireless-power/

Syllabus

UNIT – I **10 Periods**

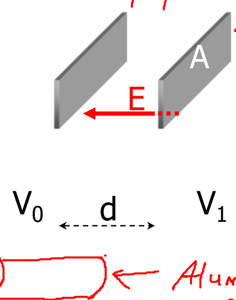
Introduction and Basic Concepts: Concept of Potential difference, voltage, current - Fundamental linear passive and active elements to their functional current-voltage relation - Terminology and symbols in order to describe electric networks - Concept of work, power, energy and conversion of energy- Principle of batteries and application.
Principles of Electrostatics: Electrostatic field - electric field intensity - electric field strength - absolute permittivity - relative permittivity - capacitor composite – dielectric capacitors - capacitors in series & parallel - energy stored in capacitors - charging and discharging of capacitors.

Capacitors: the basics

What is a capacitor?

- device for **storing charge**
- simplest example: two parallel conducting plates separated by air

→ dielectric
→ mica
→ paper



Aluminium foil.

assortment of capacitors

Capacitance

How much charge can a capacitor store?

Better question: How much charge can a capacitor store per voltage?

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

V is really $|\Delta V|$, the potential difference across the capacitor

capacitance C is a **device property**, it is always positive

unit of C: farad (F)
1 F is a large unit, most capacitors have values of C ranging from picofarads to microfarads (pF to μF).

micro $\Rightarrow 10^{-6}$, nano $\Rightarrow 10^{-9}$, pico $\Rightarrow 10^{-12}$ (Know for exam!)

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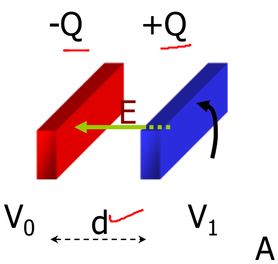
Capacitance of parallel plate capacitor

electric field between two parallel charged plates:

$$E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A}.$$



Q is magnitude of charge on either plate.

potential difference:

$$\Delta V = V_1 - V_0 = -\int_0^d \vec{E} \cdot d\vec{\ell} = E\int_0^d dx = Ed$$

capacitance:

$$C = \frac{Q}{\Delta V} = \frac{Q}{Ed} = \frac{Q}{\left(\frac{Q}{\varepsilon_0 A}\right)d} = \boxed{\frac{\varepsilon_0 A}{d}}$$

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Example: calculate the capacitance of a capacitor whose plates are 20 cm x 3 cm and are separated by a 1.0 mm air gap.

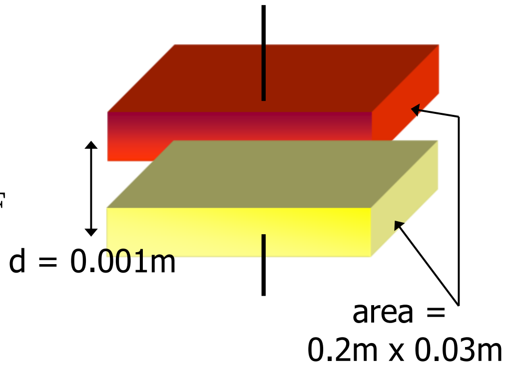
$$C = \frac{\varepsilon_0 A}{d}$$

$$C = \frac{\left(8.85\times10^{-12}\right)\left(0.2\times0.03\right)}{0.001}\ \mathrm{F}$$

$$C = 53\times10^{-12}\ \mathrm{F}$$

$$\boxed{C = 53\ \mathrm{pF}}$$

C =



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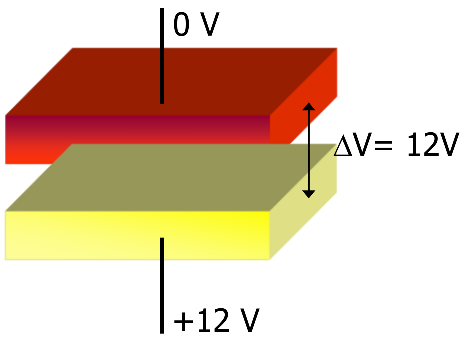
Example: what is the charge on each plate if the capacitor is connected to a 12 volt* battery?

$$Q = CV$$

$$Q = \left(53\times10^{-12}\right)\left(12\right)\mathrm{C}$$

$$\boxed{Q = 6.4\times10^{-10}\ \mathrm{C}}$$

Q = 637.2 pC



*Remember, it's the potential difference that matters.

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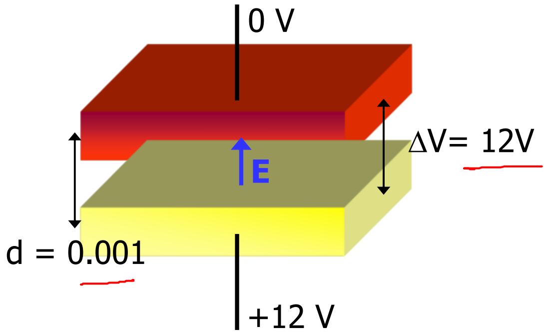
Example: what is the electric field between the plates?

$$E = \frac{\Delta V}{d}$$

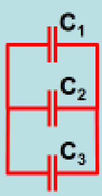
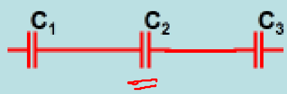
$$E = \frac{12V}{0.001\ m}$$

$$\boxed{\vec{E} = 12000\ \frac{V}{m}\ ,\text{"up."}}$$

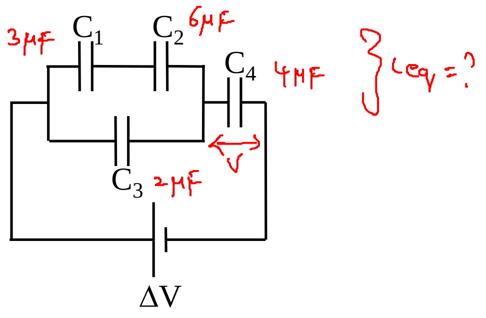


$E = 12{,}000\ V/m$

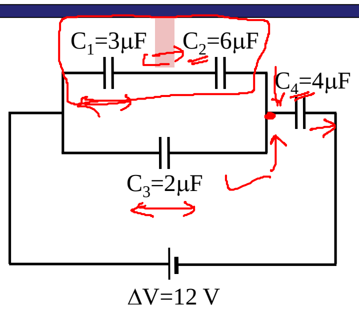
Capacitors in Series and Parallel

	Parallel	Series
		
equivalent capacitance	$C_{eq} = \sum_i C_i$	$\frac{1}{C_{eq}} = \sum_i \frac{1}{C_i}$
charge	Q's add	V's add
voltage	same V	same Q

Example: for the capacitor circuit shown, $C_1 = 3\mu F$, $C_2 = 6\mu F$, $C_3 = 2\mu F$, and $C_4 = 4\mu F$. (a) Find the equivalent capacitance. (b) if $\Delta V = 12$ V, find the potential difference across C_4.

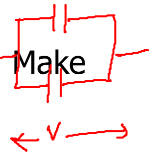


(a) Find C_{eq}. (b) if $\Delta V = 12$ V, find V_4.



C_1 and C_3 are not in parallel. Make sure you understand why!

C_2 and C_4 are not in series. Make sure you understand why!



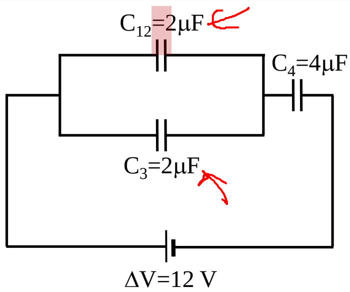
C_1 & C_2 →
C_1 & C_3 →

C_1 and C_2 are in series. Make sure you use the correct equation!

$$\frac{1}{C_{12}} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{3} + \frac{1}{6} = \frac{2}{6} + \frac{1}{6} = \frac{3}{6} = \frac{1}{2}$$

Don't forget to invert: $C_{12} = 2\ \mu F$.

(a) Find C_{eq}. (b) if ΔV=12 V, find V_4.



C_{12} and C_4 are not in series. Make sure you understand why!

C_{12} and C_3 are in parallel. Make sure you use the correct equation!

$$C_{123} = C_{12} + C_3 = 2 + 2 = \underline{4\mu F}$$

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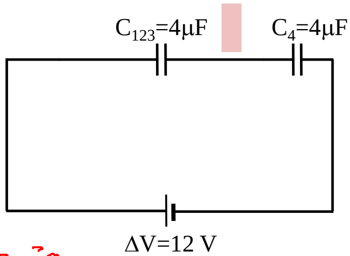
(a) Find C_{eq}. (b) if ΔV=12 V, find V_4.



√R → Ω / ammeter
→ Measure → Multimeter

C_{123} and C_4 are in series. Make sure you understand why!
Combined, they make give C_{eq}.

√C → RLC meter

$v_L = L \cdot \frac{di}{dt}$

Batteries
12V / >6V ✓
>10V
<6V ✗

Make sure you use the correct equation!

$$\frac{1}{C_{eq}} = \frac{1}{C_{123}} + \frac{1}{C_{24}} = \frac{1}{4} + \frac{1}{4} = \frac{2}{4} = \frac{1}{2}$$

L →
$i_C = C \frac{dV}{dt}$

Working ?

Don't forget to invert: $C_{eq} = \underline{2}$ μF.

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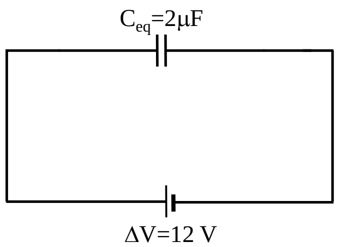
(a) Find C_{eq}. (b) if $\Delta V=12$ V, find V_4.



C_{eq} = 2 μF.

If you see a capacitor circuit on the test, read the problem first. Don't go rushing off to calculate C_{eq}. Sometimes you are asked to do other things.

Truth in advertising: there's a high probability you will need to calculate C_{eq} at some point in the problem.

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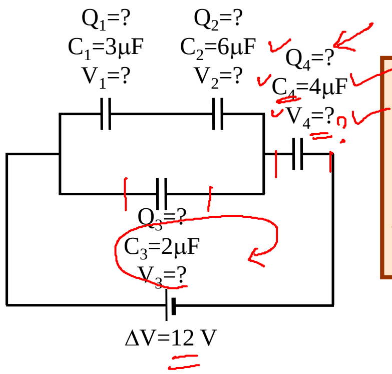
(a) Find C_{eq}. (b) if $\Delta V=12$ V, find V_4.



Hint: each capacitor has associated with it a Q, C, and V. If you don't know what to do next, near each capacitor, write down Q= , C= , and V= . Next to the = sign record the known value or a "?" if you don't know the value. As soon as you know any two of Q, C, and V, you can determine the third. This technique often provides visual clues about what to do next.

$C = \frac{Q}{V} \Rightarrow Q_4 = C V_4 \rightarrow$

We know C_4 and want to find V_4. If we know Q_4 we can calculate V_4. Maybe that is a good way to proceed.

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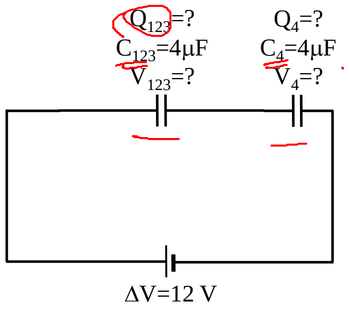
(a) Find C_{eq}. (b) if ΔV=12 V, find V_4.



C_4 is in series with C_{123} and together they form C_{eq}.

Therefore $Q_4 = Q_{123} = Q_{eq}$.

$$Q_{eq} = C_{eq}\Delta V = (2)(12) = 24\mu C = Q_4$$

$$C = \frac{Q}{V} \Rightarrow V = \frac{Q}{C} \Rightarrow V_4 = \frac{Q_4}{C_4} = \frac{24}{4} = 6V$$

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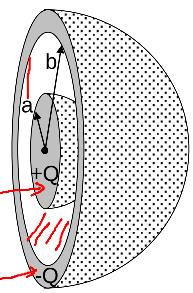
Capacitance of Concentric Spheres

If you have to calculate the capacitance of a concentric spherical capacitor of charge Q…

In between the spheres (Gauss' Law)



$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

$$|\Delta V| = \frac{Q}{4\pi\varepsilon_0}\int_a^b \frac{dr}{r^2} = \frac{Q}{4\pi\varepsilon_0}\left[\frac{1}{a} - \frac{1}{b}\right]$$

$$C = \frac{Q}{|\Delta V|} = \frac{4\pi\varepsilon_0}{\left[\frac{1}{a} - \frac{1}{b}\right]}$$

You need to do this derivation ***if*** you have a problem on spherical capacitors!

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Energy Stored in Electrostatic Field of Capacitance

- The electrostatic field of the charge stored in the dielectric has electric energy supplied by the voltage source that charges *C*.
- Energy = $\mathcal{E}$ = ½ CV^2 (joules)
  - ✓ *C* = capacitance (farads)
  - ✓ *V* = voltage across the capacitor
  - ✓ $\mathcal{E}$ = electric energy (joules)
- Stored energy is the reason why a charged capacitor can produce electric shock even when it is not connected into a circuit.

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Problem

- A parallel plate capacitor with a plate of 0.25 m2 and a plate separation of 6.00 mm is connected with 12 V source. Find:

(a)Charge on the capacitor

(b)Energy stored in the capacitor

(c)Potential difference across the capacitor is reduce to half, explain what will happen to charge on the capacitor and its stored energy

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Solution

(a) $C = \dfrac{\varepsilon_0 A}{d}$

$$= \frac{(8.854\times10^{-12})(0.25\text{m}^2)}{0.006m}$$

$$= 36.9\times10^{-9}\,F$$

(b) $U_C = \dfrac{1}{2}CV^2$

$E = \frac{1}{2}cV^2 = ?$

$$= \frac{1}{2}(36.9\times10^{-9}\,\text{F})(12\,\text{V})^2$$

$$= 2.66\times10^{-6}\,\text{J}$$

(c) Since $Q = CV$, it half.
Since $UC = ½\, CV^2$, ~~it doubles~~.

$\frac{E}{4}$

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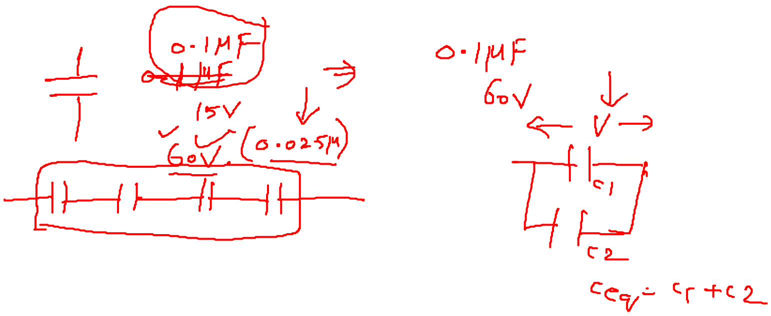
Problem

- *Given some capacitors of 0·1 μF capable of withstanding 15V.Calculate the number of capacitors needed if it is desired to obtain a capacitance of 0·1 μF for use in a circuit involving 60 V.*



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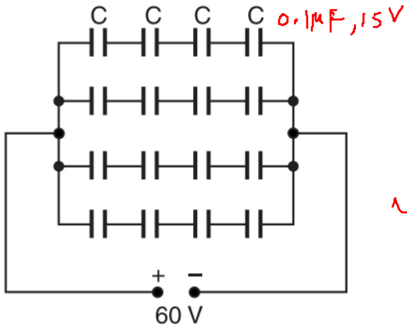

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Summary

Capacitors
- → Review
- → problems
- → Composite capacitor →
- → Synthesis