# Unit - I
# 1.8 Capacitors

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THINK MERIT | THINK TRANSPARENCY | THINK SASTRA

CSP – Concentrating Solar-thermal Power

Batteries

2017 → Zunum Aero

68

6

Eviation

↳ Alice

100 Vs 1100

Velis

Electro

S

Solar PV

↓

? → Storage

Solar thermal

# 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.

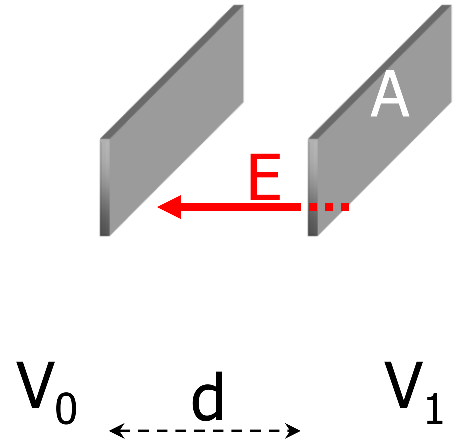
**Principles of Electrostatics:** Electrostatic field - electric field intensity - electric field strength - absolute permittivity - relative permittivity - capacitor composite – dielectric capacitors - capacitors in series & parallel - energy stored in capacitors - charging and discharging of capacitors.

# Capacitors: the basics

→ Fans

**What is a capacitor?** → TV

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




assortment of capacitors

# Capacitance

How much charge can a capacitor store? Supercapacitors

**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)

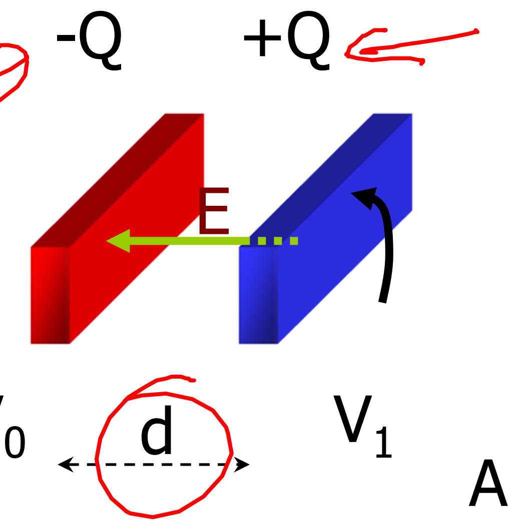
1 F is a large unit, most capacitors have values of C ranging from picofarads to microfarads (pF to $\mu$F).

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

# 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:

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

$\varepsilon = \varepsilon_0 \varepsilon_r$

capacitance:

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

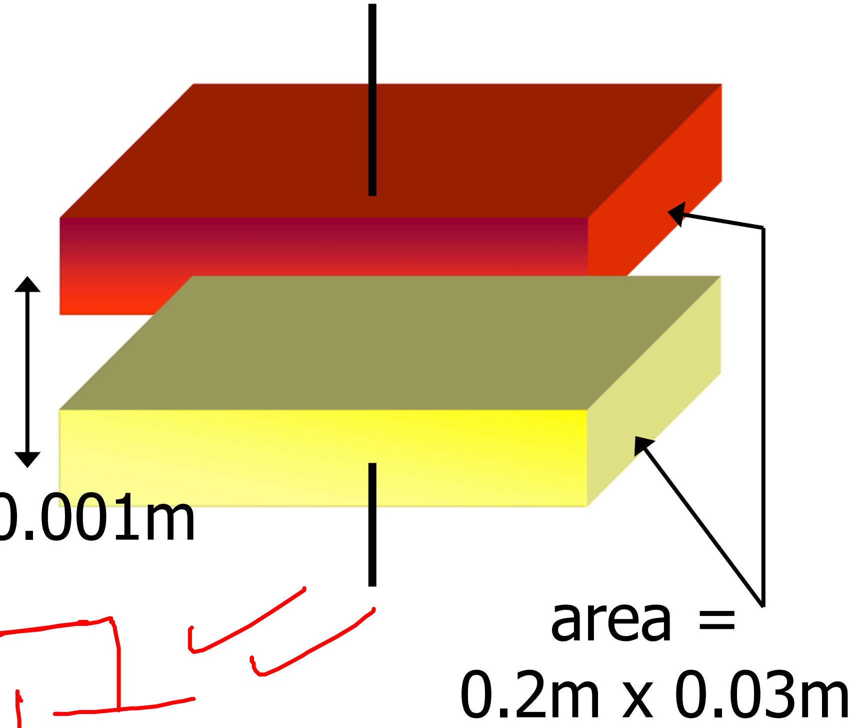
# Example: calculate the capacitance of a capacitor whose plates are 20 cm x 3 cm and are separated by a 1.0 mm air gap.

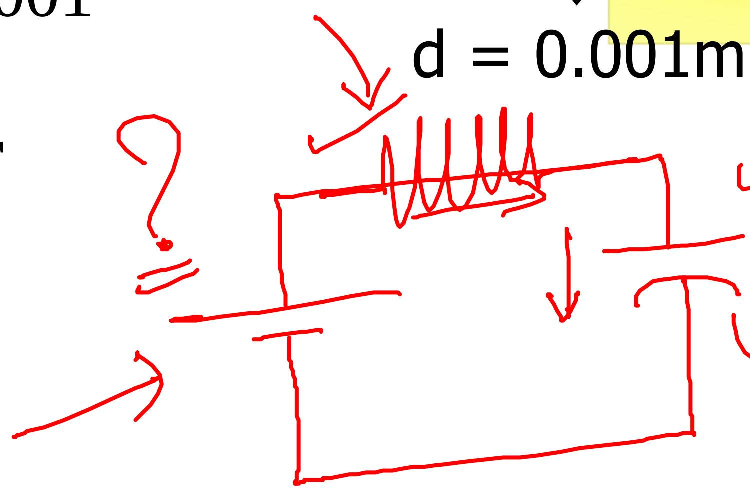
$$C = \frac{\varepsilon_0 A}{d}$$

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

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

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



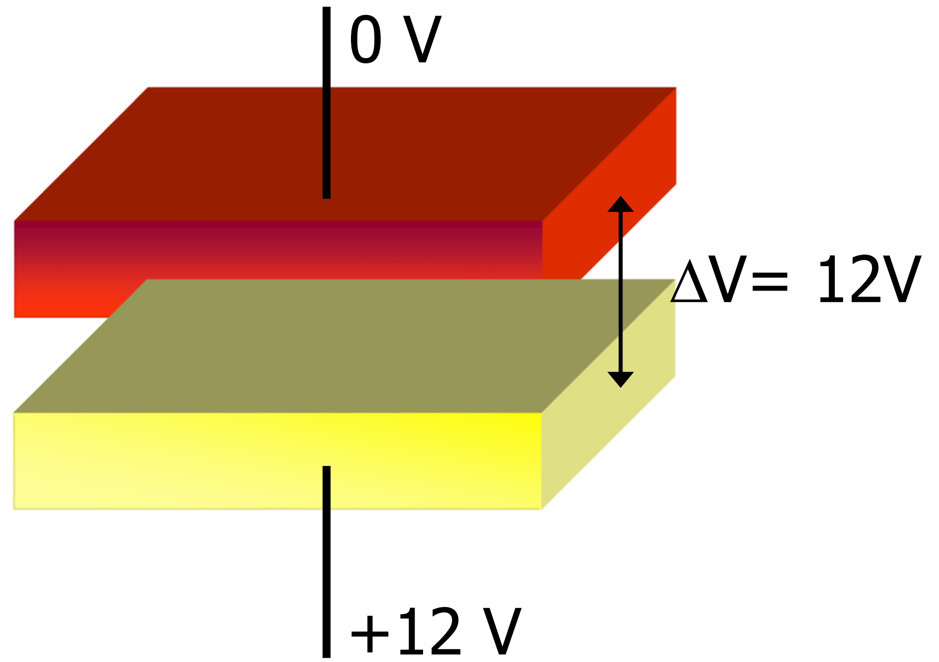
Discharged

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

$$Q = CV$$

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

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



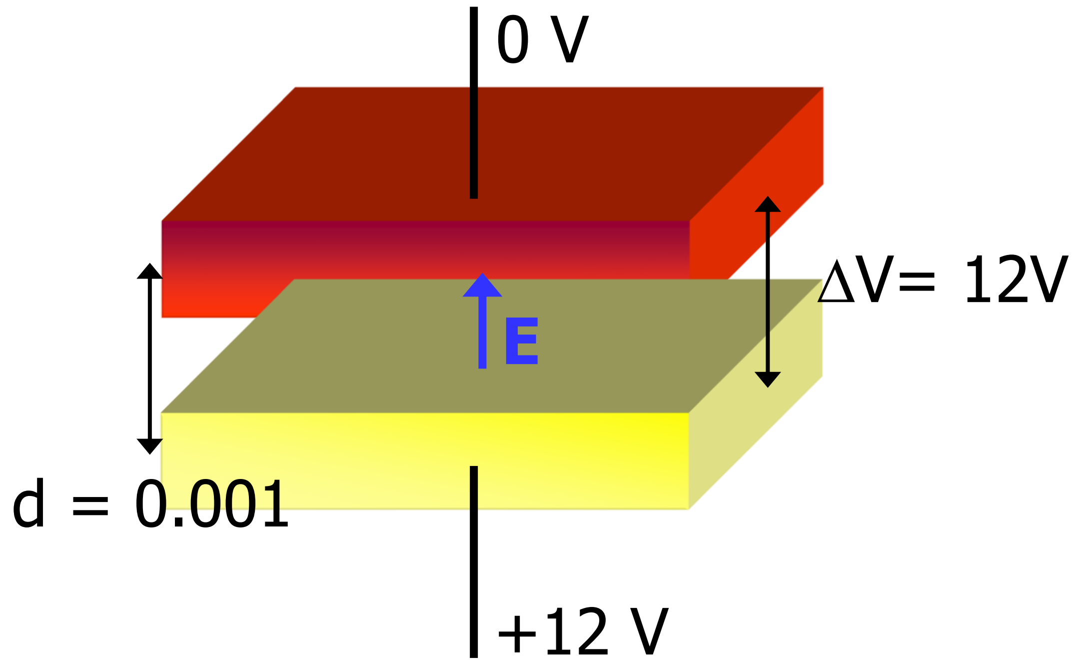

*Remember, it's the potential difference that matters.

# Example: what is the electric field between the plates?

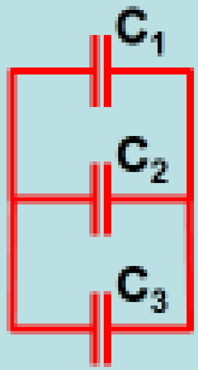
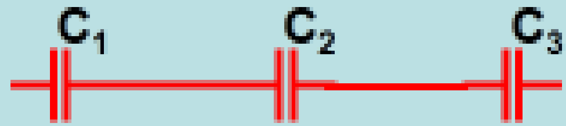
$$E = \frac{\Delta V}{d}$$

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

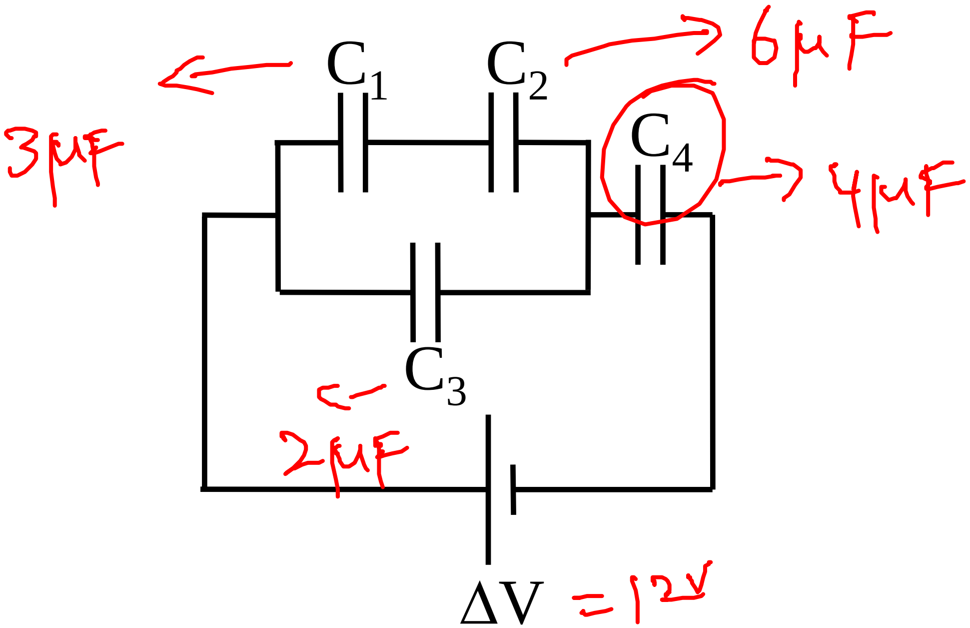
$$\boxed{\vec{E} = 12000\ \frac{\mathrm{V}}{\mathrm{m}}\ ,\text{"up."}}$$



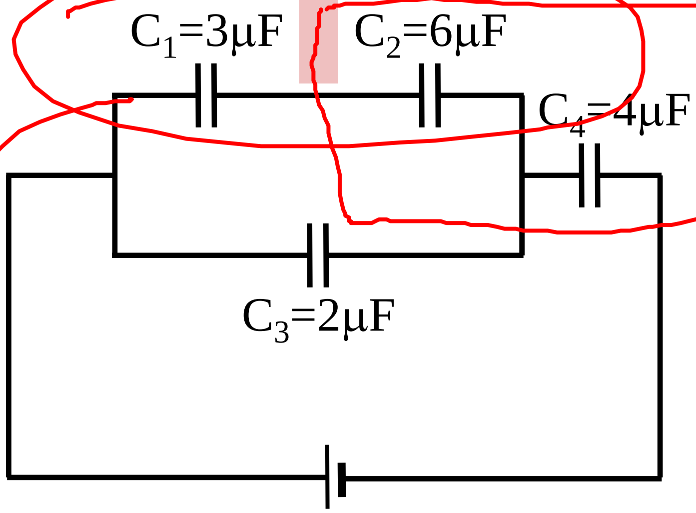
# Capacitors in Series and Parallel

| | 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!

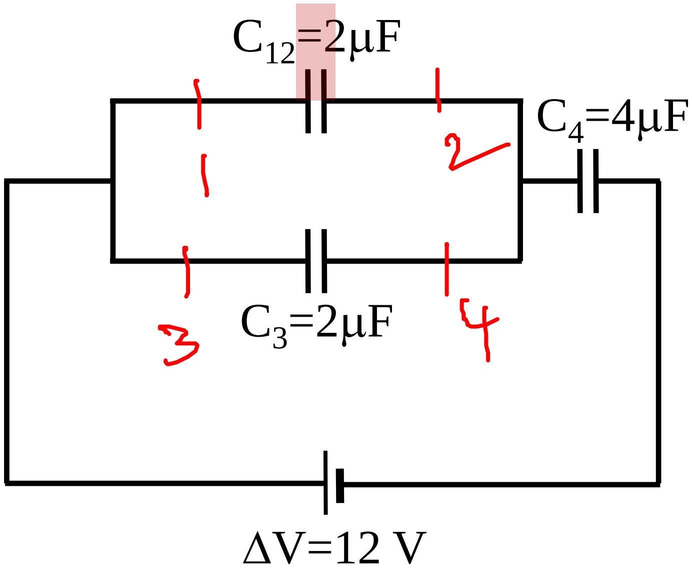
$C_2$ and $C_4$ are not in series. Make sure you understand why!

$C_1$ 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 μF.

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

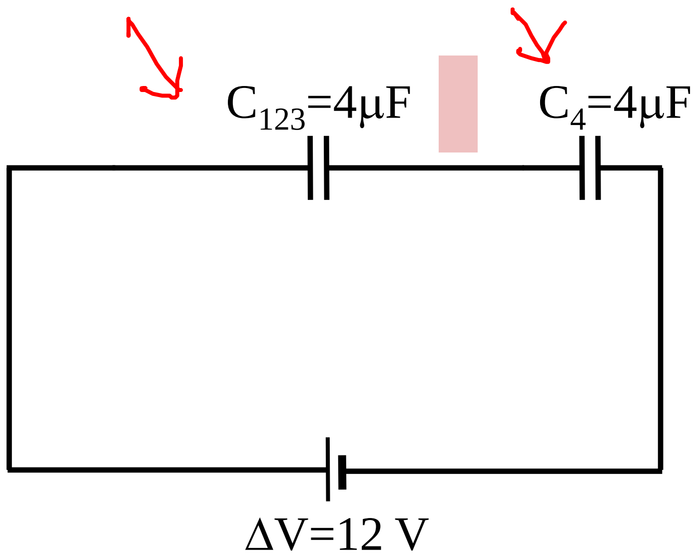



$C_{12}$ and $C_4$ are not in series. Make sure you understand why!

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

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

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



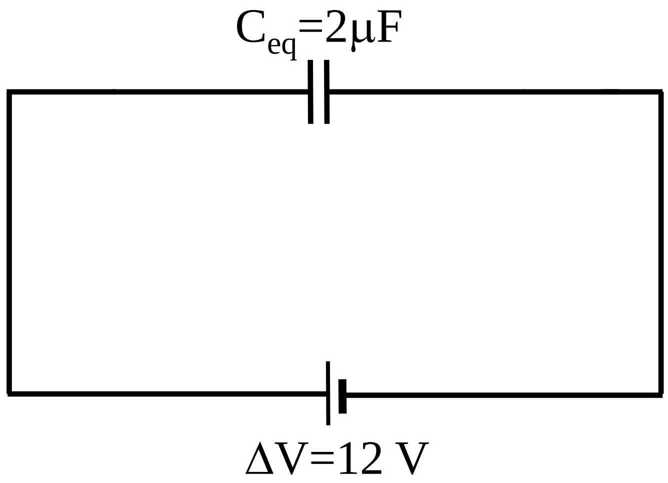

$C_{123}$ and $C_4$ are in series. Make sure you understand why! Combined, they make give $C_{eq}$.

Make sure you use the correct equation!

$$\frac{1}{C_{eq}} = \frac{1}{C_{123}} + \frac{1}{C_4} = \frac{1}{4} + \frac{1}{4} = \frac{2}{4} = \frac{1}{2}$$

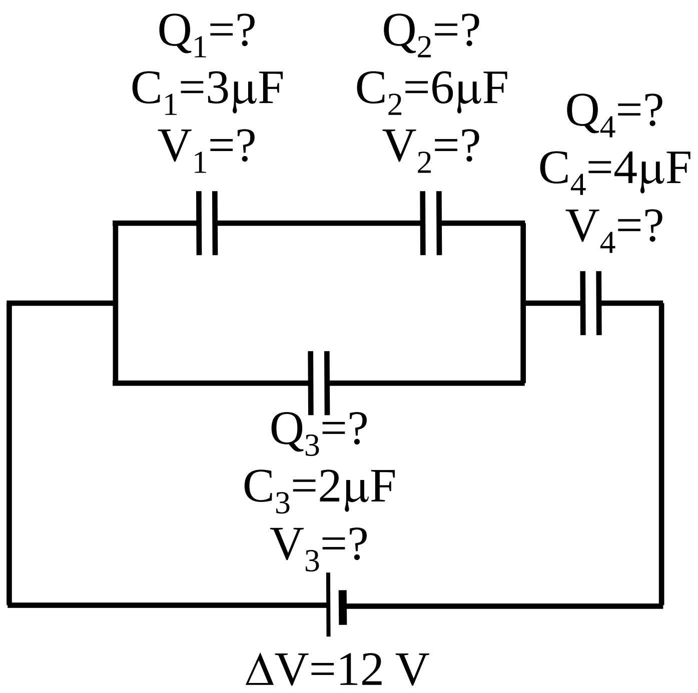
Don't forget to invert: $C_{eq}$ = 2 μF.

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




$C_{eq} = 2\ \mu F$.

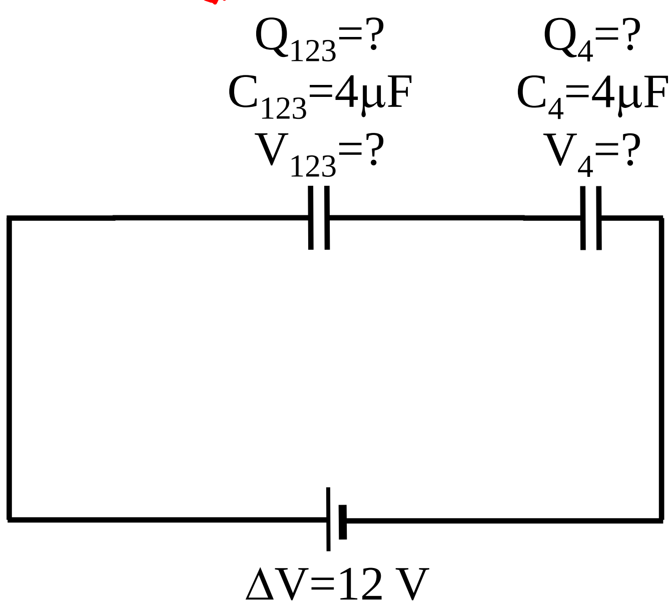
# (a) Find $C_{eq}$. (b) if $\Delta V$=12 V, find $V_4$.

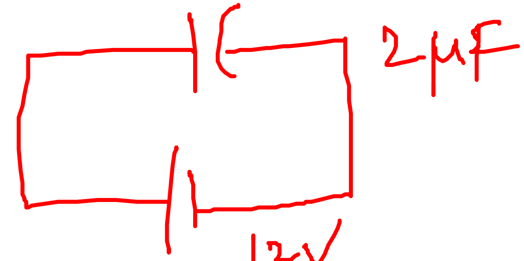



**Hint**: each capacitor has associated with it a Q, C, and V. If you don't know what to do next, near each capacitor, write down Q= , C= , and V= . Next to the = sign record the known value or a "?" if you don't know the value. As soon as you know any two of Q, C, and V, you can determine the third.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

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.

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




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

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

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

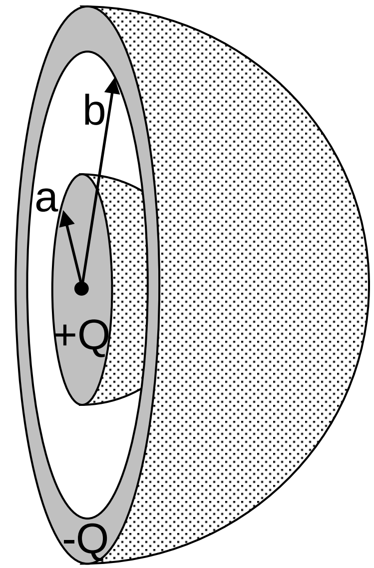
$$C = \frac{Q}{V} \Rightarrow \underline{V} = \frac{Q}{C} \Rightarrow V_4 = \frac{Q_4}{C_4} = \frac{24}{4} = \underline{6V}$$

# 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!

# 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 = $\boldsymbol{\varepsilon}$ = ½ $CV^2$ (joules)

- ✓ $C$ = capacitance (farads)
- ✓ $V$ = voltage across the capacitor
- ✓ $\boldsymbol{\varepsilon}$ = 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.

# 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

$C = \frac{\epsilon_0 A}{d}$

(b) Energy stored in the capacitor

$U_c = \frac{1}{2} C V^2$

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

## Solution

(a) $$C = \frac{\varepsilon_o A}{d}$$

$$= \frac{(8.854 \times 10^{-12})(0.25 m^2)}{0.006 m}$$

$$= 36.9 \times 10^{-9} F$$

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

$$= \frac{1}{2} (36.9 \times 10^{-9} \text{ F})(12 \text{ V})^2$$

$$= 2.66 \times 10^{-6} \text{ J}$$

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

# Problem

Synthesis

- *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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# Summary

Capacitors → Electrostatics

- → Definition
- → Equations
- → Series / parallel
- → Energy

Synthesis ?