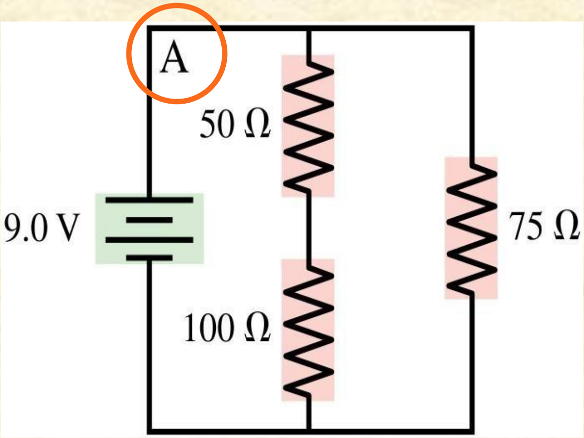
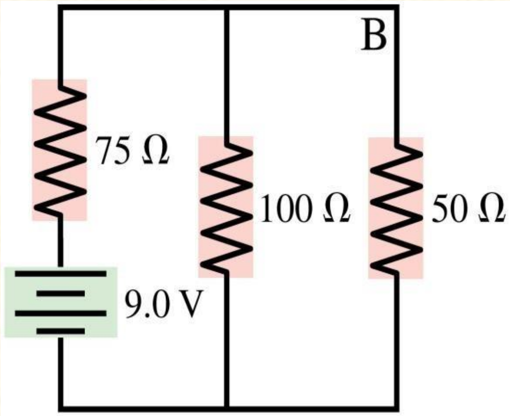
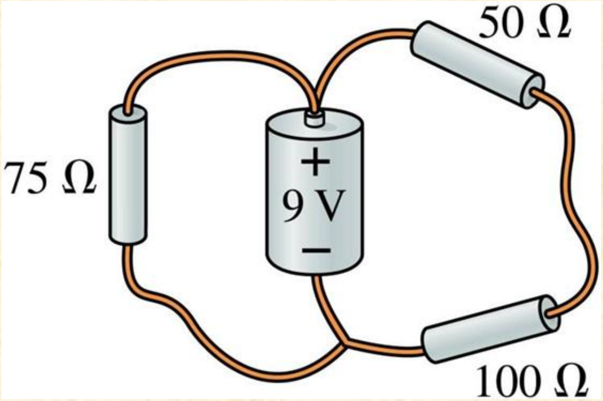
Lecture 4

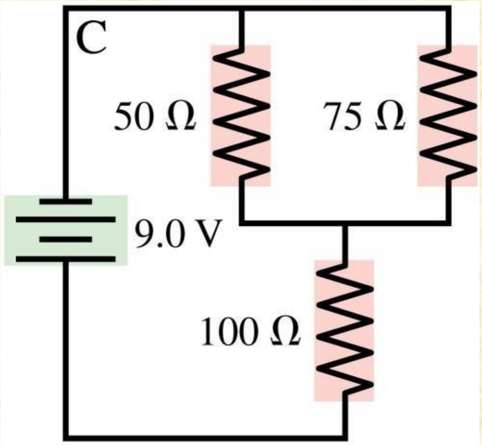
Capacitor

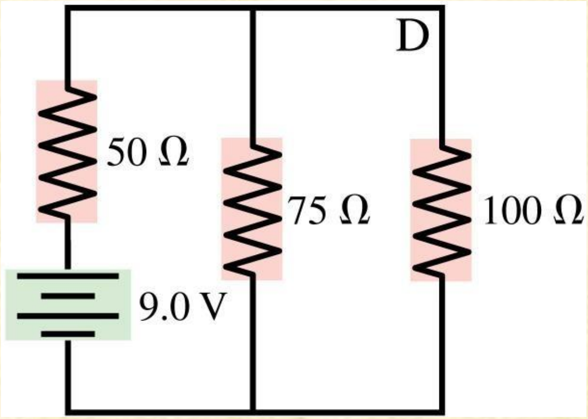
Which is the correct circuit diagram for the circuit shown?





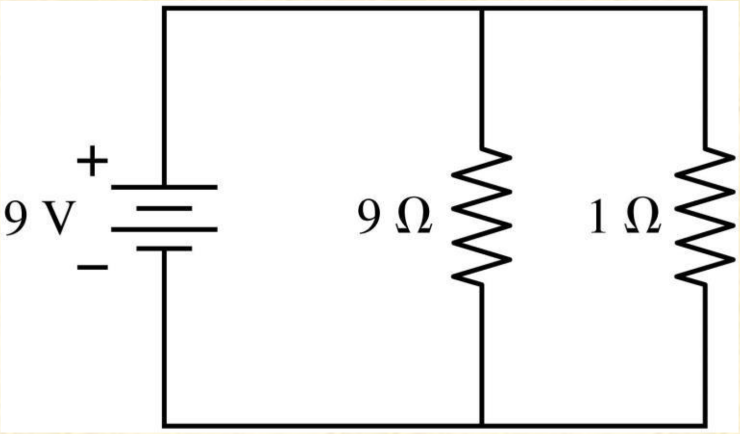






Electrical Basics

Which resistor dissipates more power?

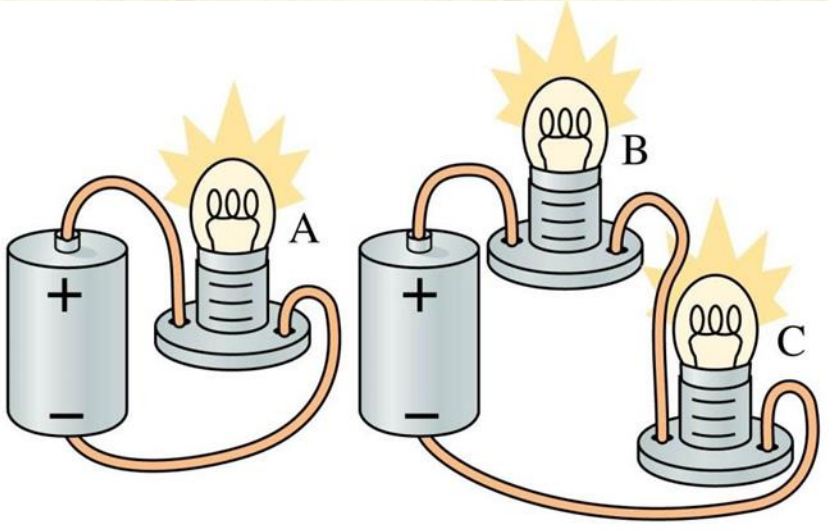


1. The 9 Ω resistor
2. The 1 Ω resistor
3. They dissipate the same power

$$P = \frac{(\Delta V)^2}{R}$$

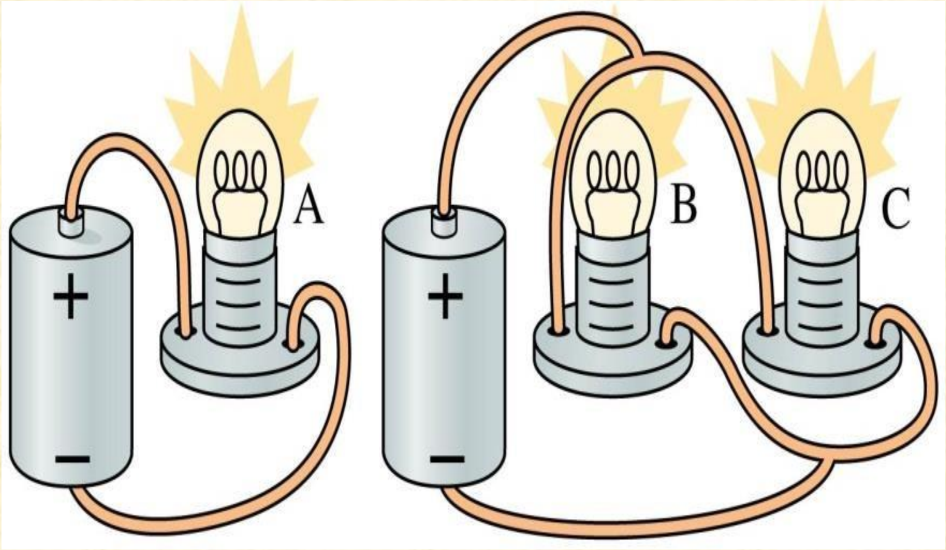
The three bulbs are same and the two batteries are same . Compare the brightnesses of the bulbs.

A. $A > B > C$
B. $A > C > B$
C. $\boxed{A > B = C}$
D. $A < B = C$
E. $A = B = C$



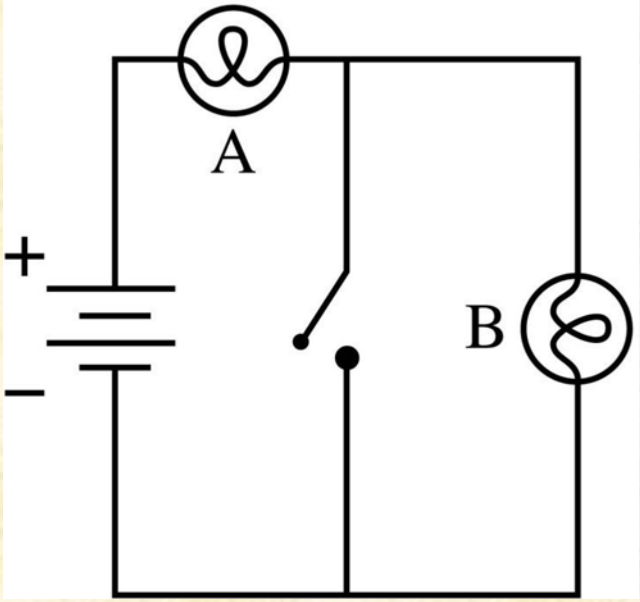
The three bulbs are same and the two batteries are same . Compare the brightnesses of the bulbs.

A. $A > B > C$
B. $A > C > B$
C. $A > B = C$
D. $A < B = C$
E. $\boxed{A = B = C}$



The lightbulbs are same. Initially both bulbs are glowing. What happens when the switch is closed?

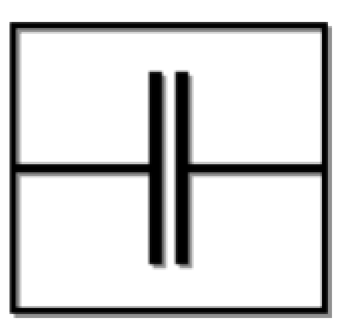
A. Nothing.
B. A stays the same; B gets dimmer.
C. A gets brighter; B stays the same.
D. Both get dimmer.
E. A gets brighter; B goes out.



Introduction to Electricity

Capacitor

A capacitor is an electronic device that stores an electrical charge between the two plates



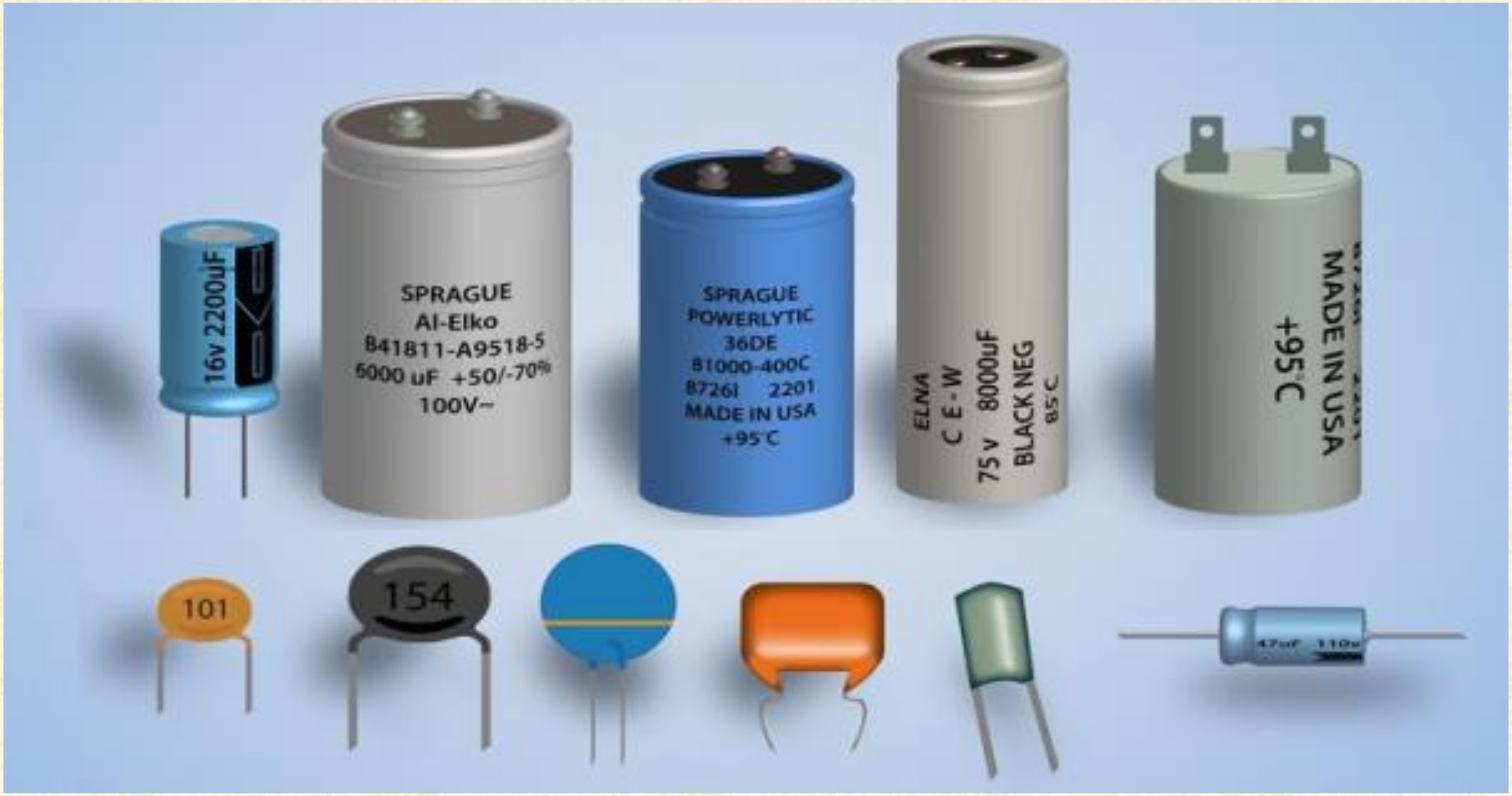
Unit of Capacitor Farad (F)

Symbol of Capacitor (C)

Capacitor properties

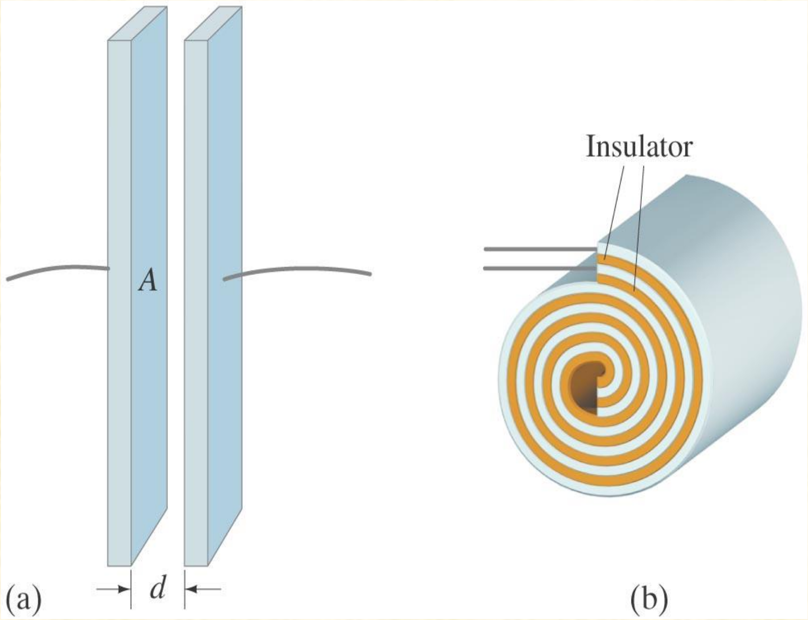
1. When a capacitor has a difference in voltage (electrical pressure) across its plate, it is said to be charged.
2. A capacitor is charged by having a one-way current flow through it for a period of time.
3. It can be discharged by letting a current flow in the opposite direction out of the capacitor.

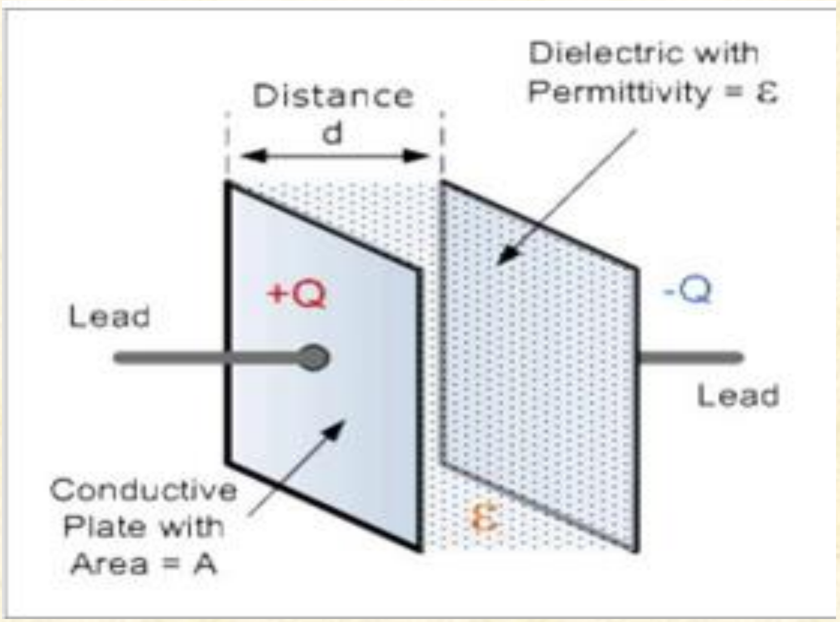
Introduction to Electricity



Capacitor Construction

- A capacitor is constructed using a pair of parallel conducting plates separated by an insulating material (dielectric).

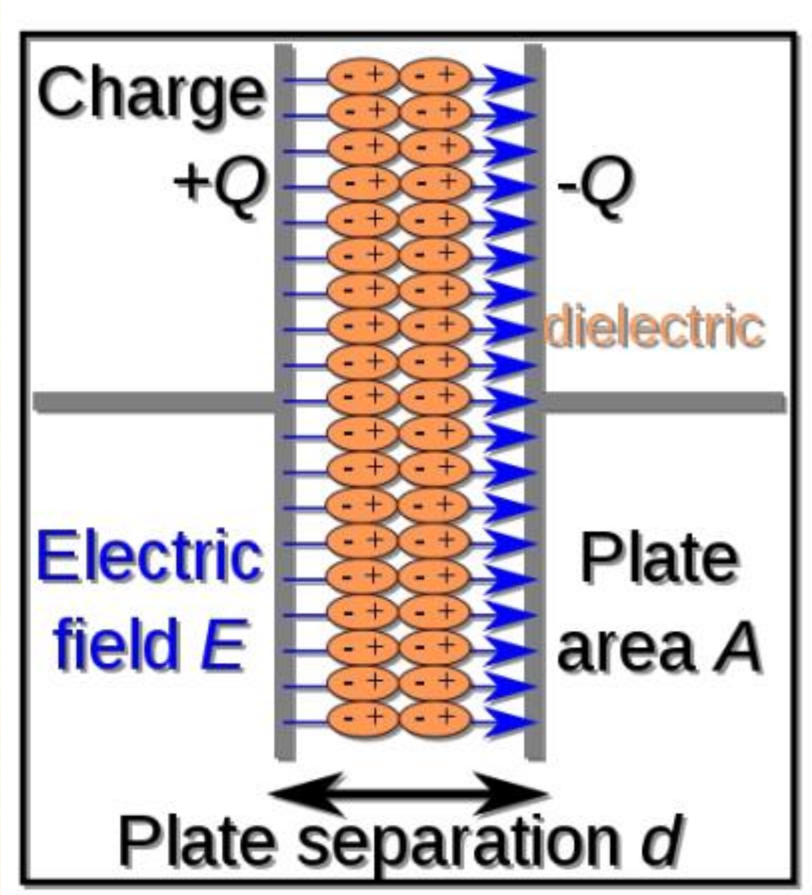




Capacitor Construction

What is dielectric?

The dielectric constant of a material determines the amount of energy that a capacitor can store when voltage is applied.



Capacitance

An analogy:

Imagine you store rubber bands in a bottle that is nearly full.

You could store more rubber bands (like charge or Q) in a bigger bottle (capacitance or C) *or* if you push them in with more force (voltage or V). Thus,

$$Q = CV$$

Capacitor definition

Capacitance

Capacitance (C) is the ratio of charge to voltage

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

Rearranging, the amount of charge on a capacitor is determined by the size of the capacitor (C) and the voltage (V).

$$Q = CV$$

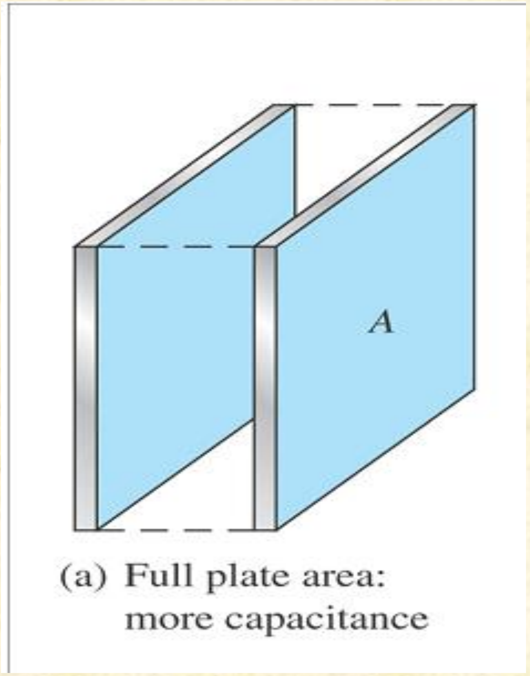
If a 22 μF capacitor is connected to a 10 V source, the charge is

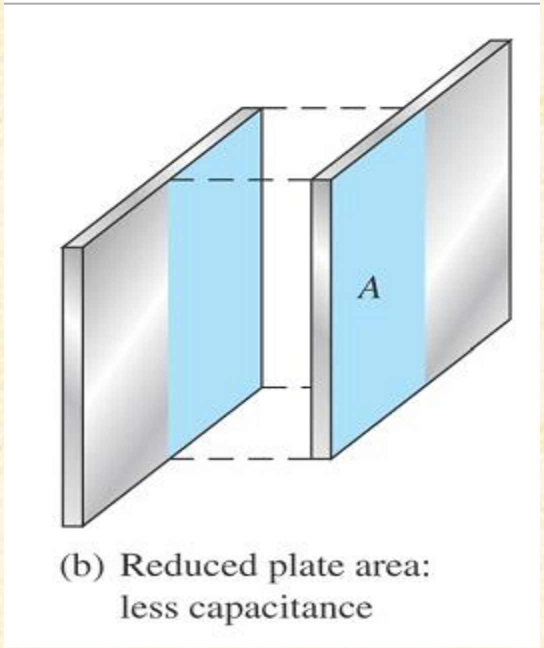
220 μC

Capacitor Characteristic

Plate area

Capacitance is directly proportional to the physical size of the plates as determined by the plate area



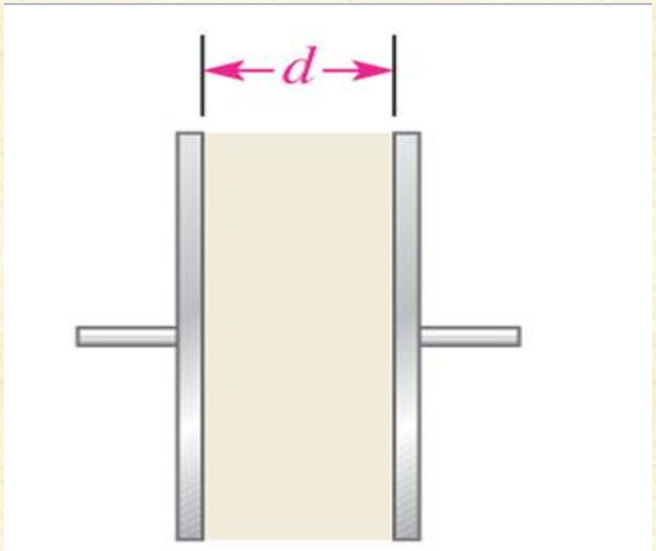


Less plate area = Less Capacitance

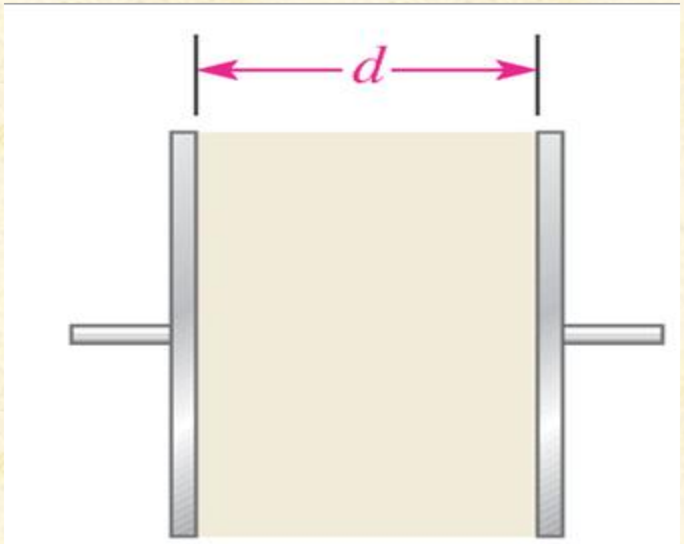
Capacitor Characteristic

Separates plates

Capacitance is inversely proportional to the distance between the plates



(a) More capacitance



(b) Less capacitance

More distance between plates = Less Capacitance

Capacitor Characteristic

Dielectric

The dielectric material provides the insulation between the capacitor plates, and in addition this it determines many of the characteristics of the capacitor.

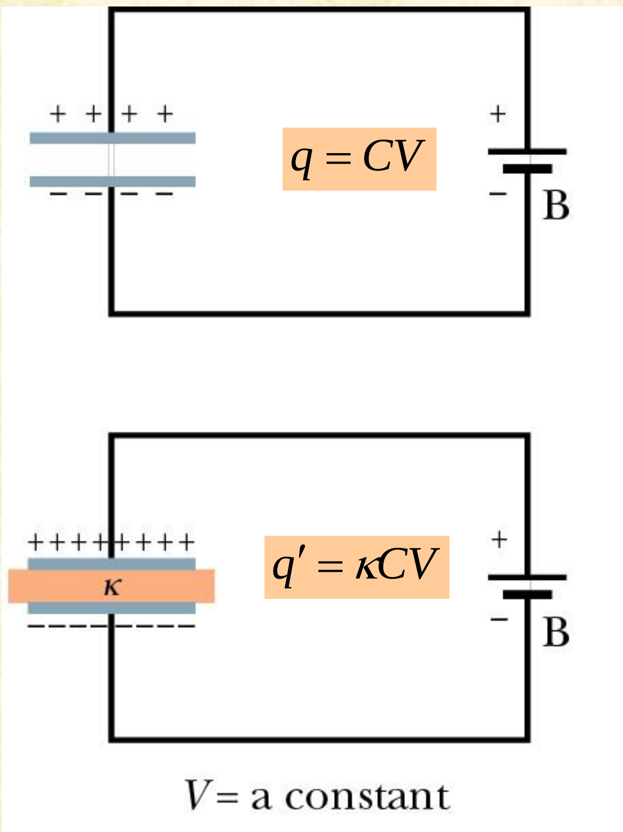
It is that property of a dielectric material that determines how much electrostatic energy can be stored per unit of volume when unit voltage is applied, and as a result it is of great importance for capacitors and capacitance calculations.

Material	Dielectric Constant κ
Air	1.00054
Polystyrene	2.6
Paper	3.5
Transformer Oil	4.5
Pyrex	4.7
Ruby Mica	5.4
Porcelain	6.5
Silicon	12
Germanium	16
Ethanol	25
Water (20º C)	80.4
Water (50º C)	78.5
Titania Ceramic	130
Strontium Titanate	310

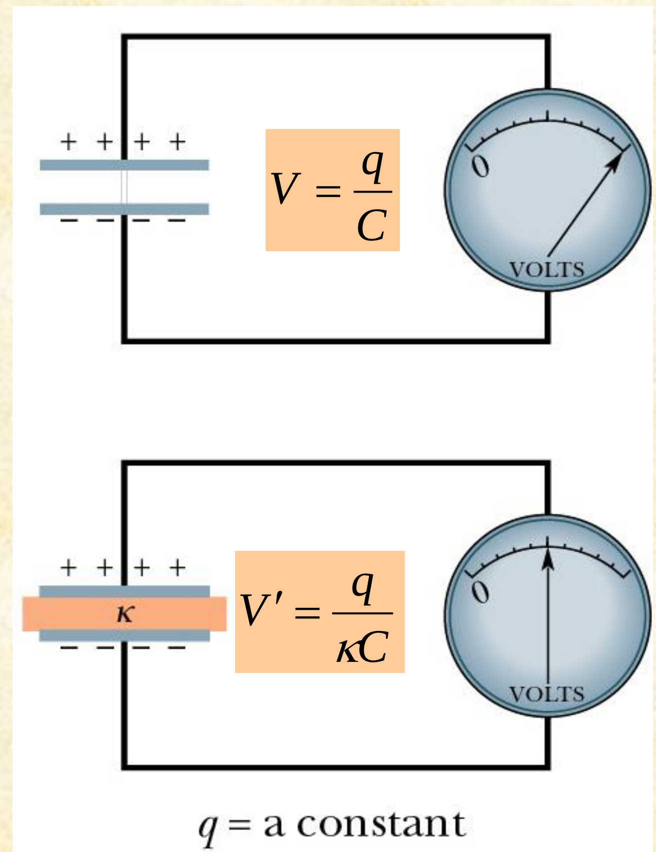
Capacitor Characteristic

What happens when dielectric is insert ?

With battery attached, V=const, so more charge flows to the capacitor



With battery disconnected, q=const, so voltage (for given q) drops.

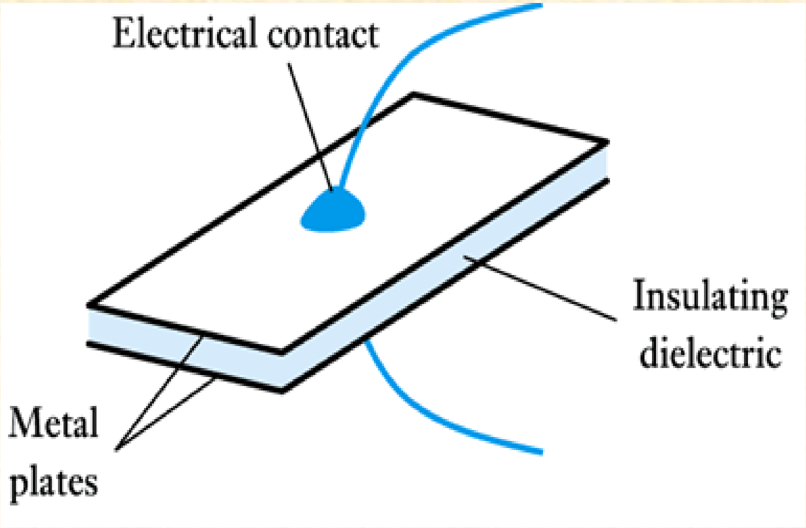


Capacitance

Capacitance (C) is directly proportional to:

The relative dielectric constant

The plate area.



Capacitance (C) is inversely proportional to:

The distance between the plates

$$C = \varepsilon_r \varepsilon_o \frac{A}{D}$$

ε_r = Relative permittivity of the Dielectric

ε_0 = permittivity of free space $8.85 * 10^{-12}\ F/m$

A = Plate area

D = Separation distance of plate.

Capacitance

Three factors affecting the value of capacitance:

$$C = \varepsilon \frac{A}{D}$$

1. Area: the larger the area, the greater the capacitance.
2. Spacing between the plates: the smaller the spacing, the greater the capacitance.
3. Material permittivity: the higher the permittivity, the greater the capacitance.

Capacitor Characteristic

Example :

Find the capacitance of a 4.0 cm diameter sensor immersed in oil if the plates are separated by 0.25 mm. $\left(\varepsilon_r = 4.0 \text{ for oil}\right)$

$$C = 8.85\times10^{-12}\,\text{F/m}\left(\frac{\varepsilon_r A}{d}\right)$$

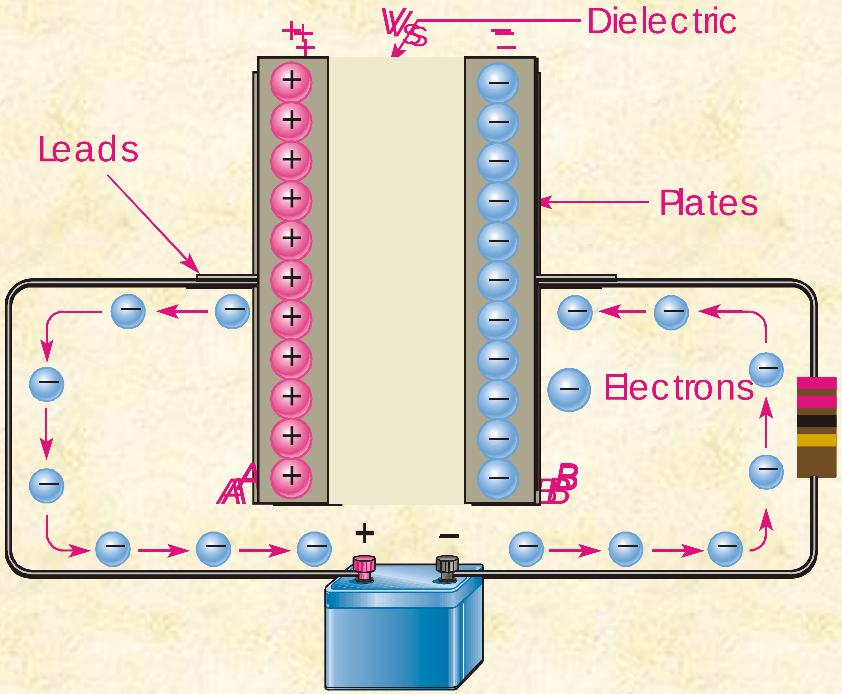
The plate area is $A = \pi r^2 = \pi\left(0.02\text{ m}^2\right) = 1.26\times10^{-3}\text{ m}^2$

The distance between the plates is $0.25\times10^{-3}\text{ m}$

$$C = 8.85\times10^{-12}\,\text{F/m}\left(\frac{(4.0)\left(1.26\times10^{-3}\text{ m}^2\right)}{0.25\times10^{-3}\text{ m}}\right) = 178\text{ pF}$$

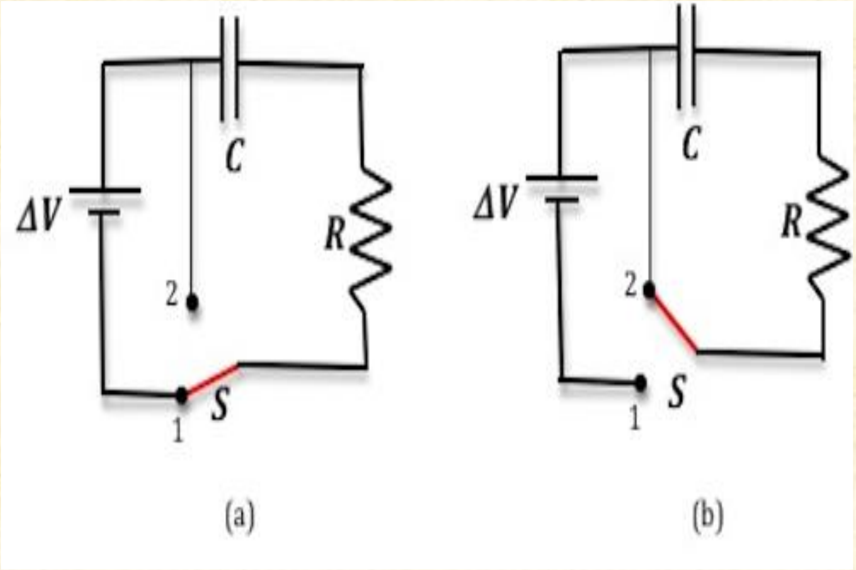
Charging a capacitor

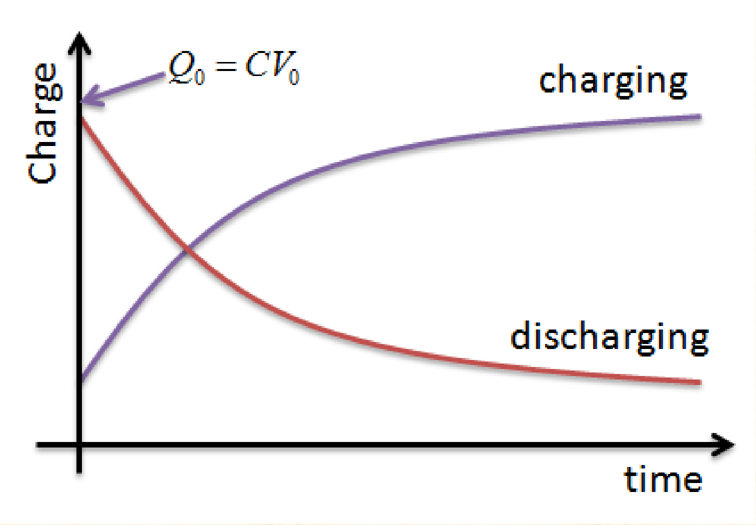
The charging process…



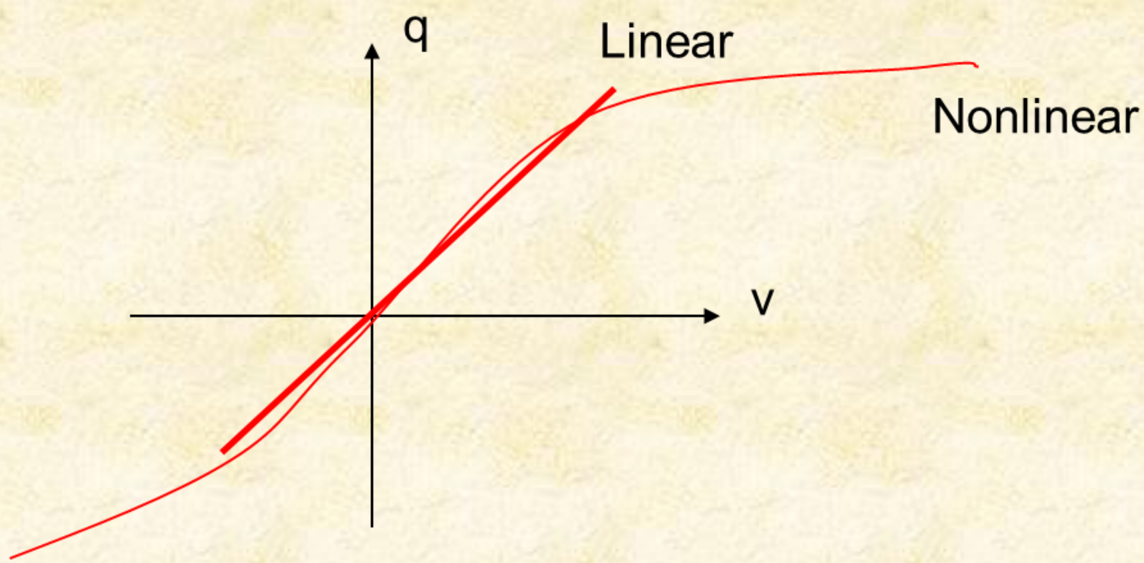
A capacitor with stored charge can act as a temporary battery.

Discharging a capacitor





Voltage Limit on a Capacitor

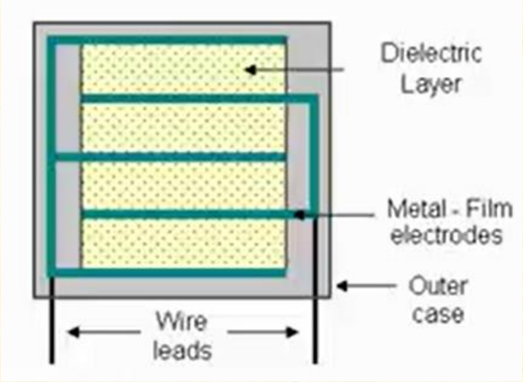


$$q = Cv$$

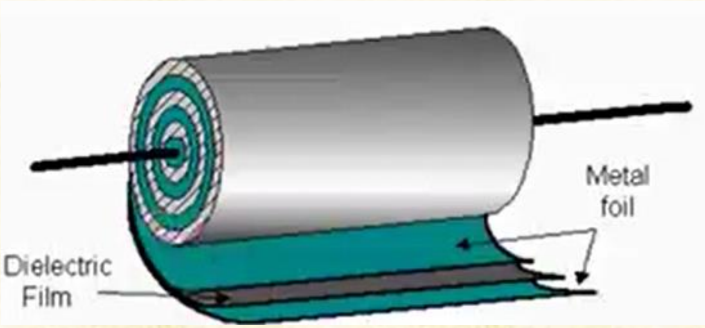
Since q=Cv, the plate charge increases as the voltage increases. The electric field intensity between two plates increases. If the voltage across the capacitor is so large that the field intensity is large enough to break down the insulation of the dielectric, the capacitor is out of work. Hence, every practical capacitor has a maximum limit on its operating voltage.

Capacitor types

Capacitors have two main different type in the shape construction



Redial lead type



Axial lead type

Main types of capacitor

Ceramic capacitors

Plastic film capacitors

Electrolytic capacitors

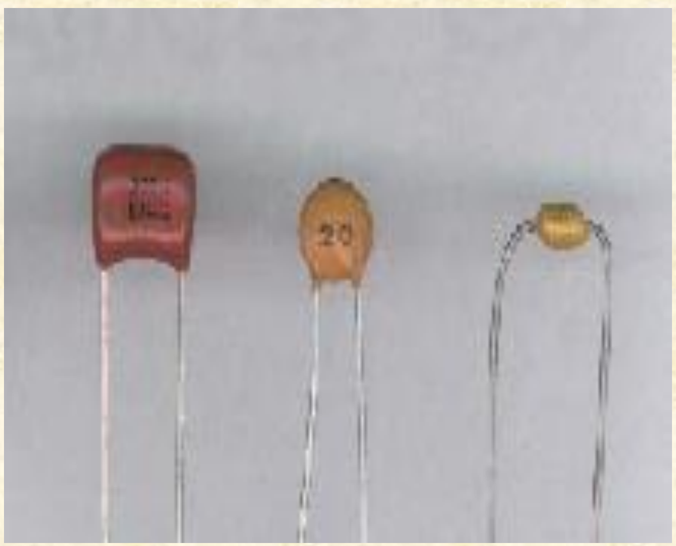
Mica capacitors

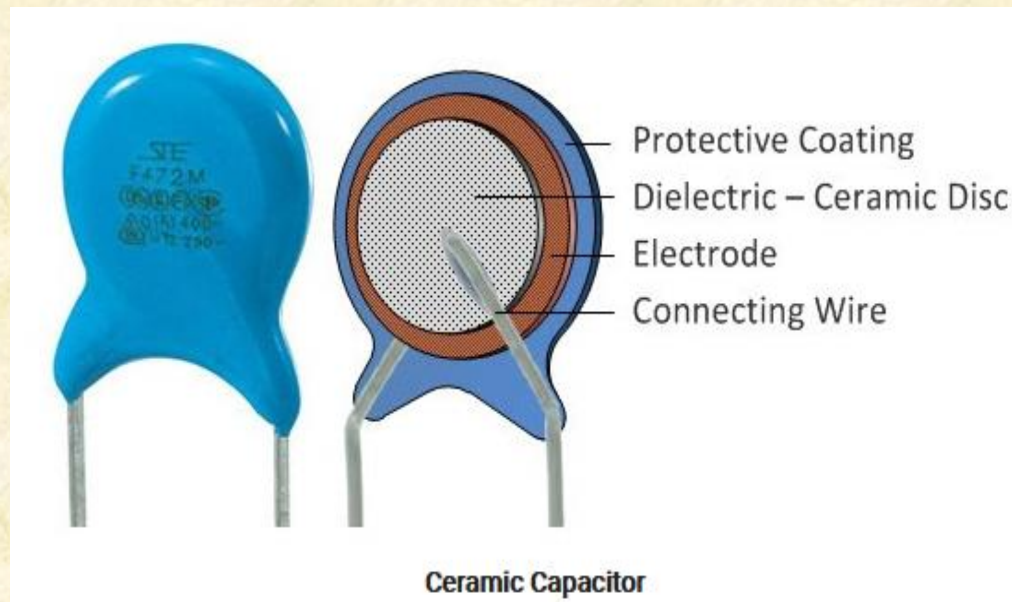
Capacitor types

Fixed Capacitors

Ceramic capacitors

Ceramic capacitors are small nonpolarized capacitors They have relatively high capacitance due to high ε_r.





Capacitor types

Ceramic capacitors properties

Very popular nonpolarized capacitor

Small, inexpensive, but poor temperature stability and poor accuracy

Ceramic capacitors provide very high dielectric constants, and relatively large capacitance in a small physical size

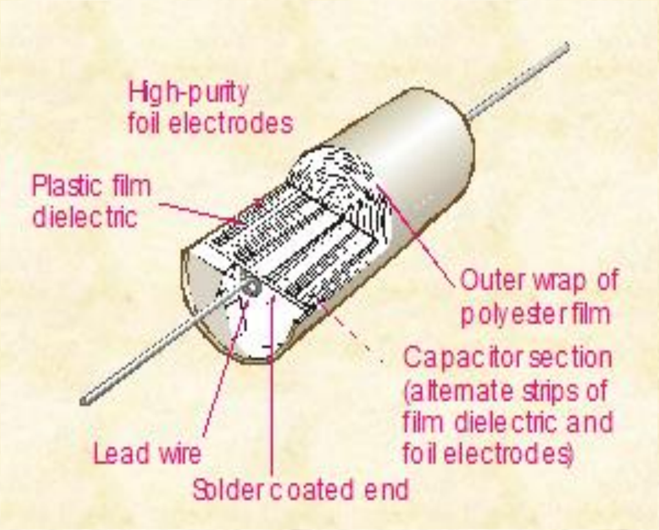
Capacitance ranges are from 1pF to 2.2μF

Often used for bypass and coupling applications

Capacitor types

Plastic film capacitors

Plastic film capacitors are small and nonpolarized. They have relatively high capacitance due to larger plate area.

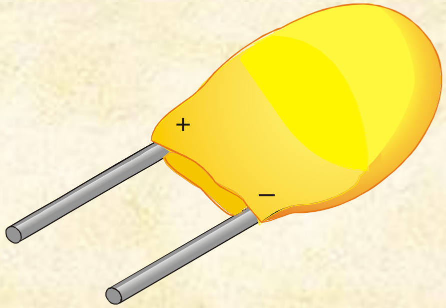


Capacitor types

Electrolytic capacitors

Axial lead

Radial lead



polarized

Two common types of electrolytic capacitors are **Aluminum** and **Tantalum** electrolytic

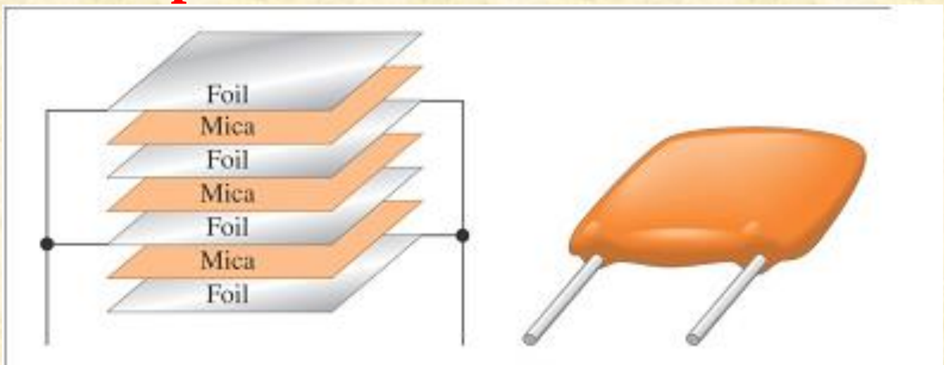
Tantalum electrolytic capacitor has a larger capacitance when compared to aluminum electrolytic capacitor

Electrolytic capacitors have higher capacitance but lower voltage ratings and higher leakage current

Bad temperature stability, high leakage, short lives

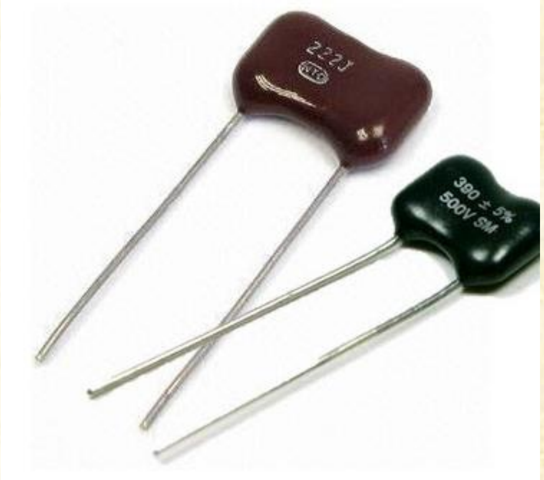
Capacitor types

Mica capacitors



(a) Stacked layer arrangement

(b) Layers are pressed together and encapsulated.



Mica Capacitor

Stacked-foil mica capacitors are made of alternate layers of metal foil and thin sheets of mica

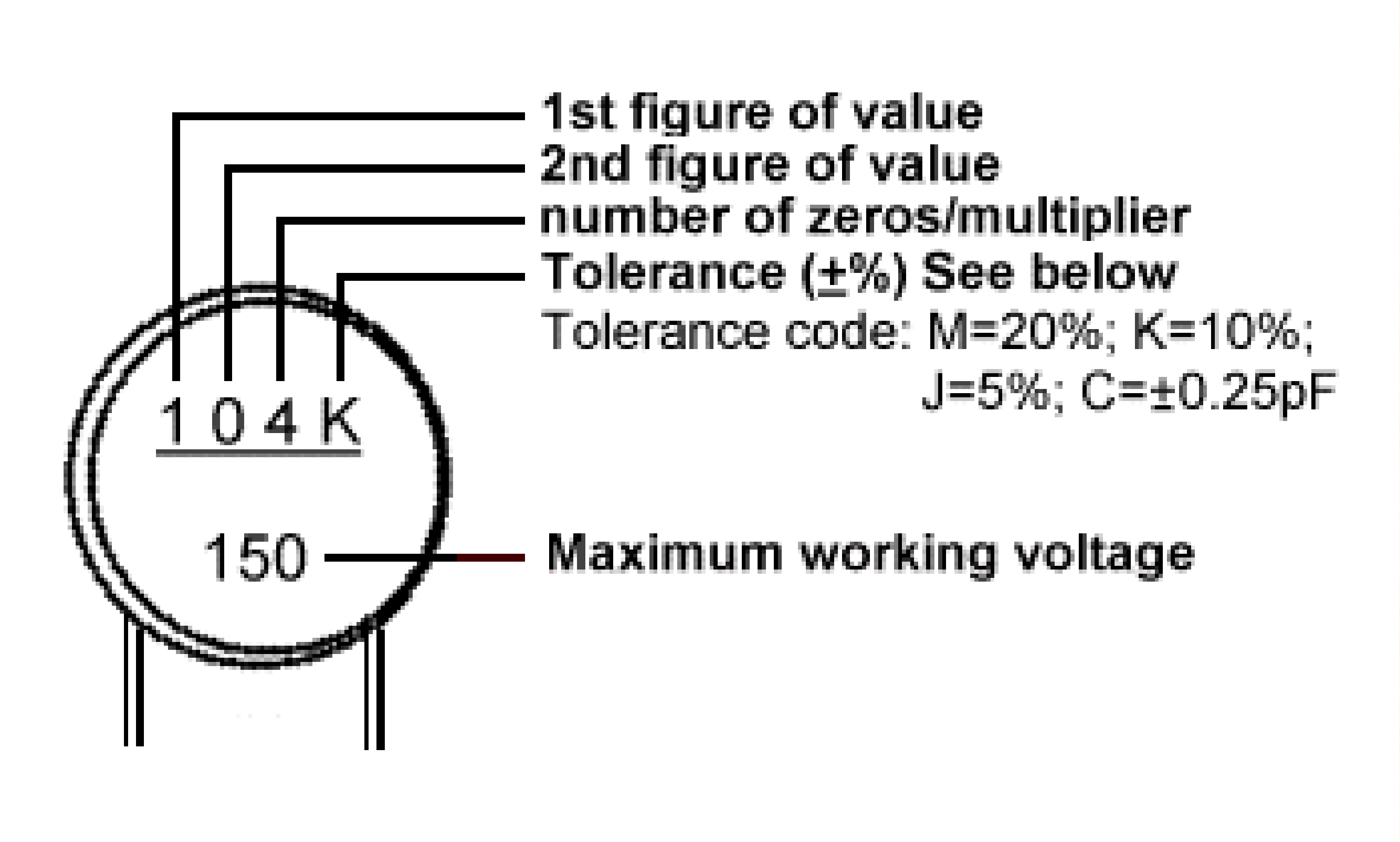
Silver mica are formed by stacking mica sheets with silver electrode material screened on them

Range from 1pF to 0.1 uF

Low Capacitance @ High Voltage 500 V

Often used in high-frequency circuits (i.e. RF circuits)

Capacitor Reading Example



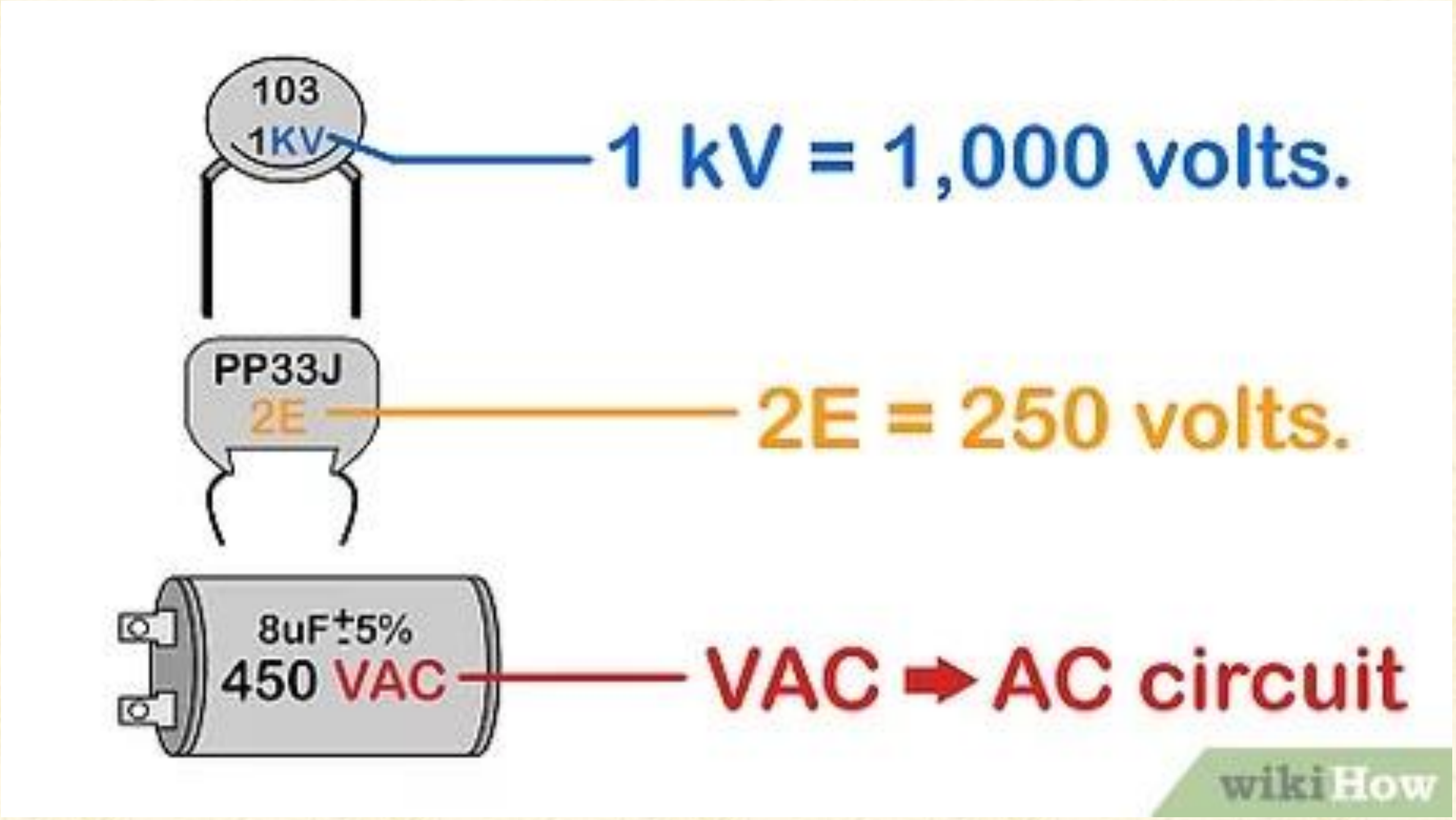
$$10\times10^{4}\,\text{pF}=10^{5}\times10^{-12}\,\text{F}=10^{-7}\,\text{F}=0.1\times10^{-6}\,\text{F}=0.1\mu\text{F}$$

- Thus, we have a 0.1μF capacitor with ±10% tolerance.

Capacitor Reading Example

$$10 \times 10^{3}\,pF = 10^{4} \times 10^{-12}\,F = 10^{-8}\,F = 0.01 \times 10^{-6}\,F = 0.01\mu F$$

Capacitor Reading Example



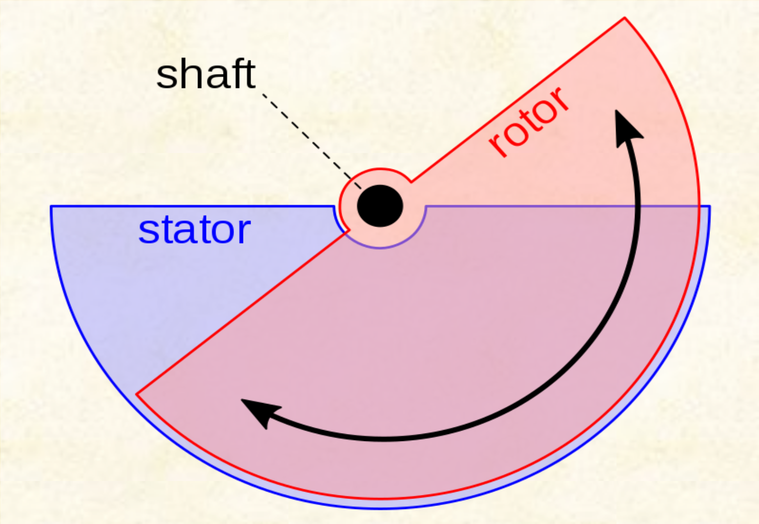
Capacitor types

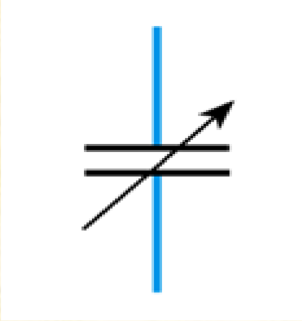
Variable Capacitors

Variable capacitors typically have small capacitance values and are usually adjusted manually.

Ceramic or mica is a common dielectric

is a need to adjust the capacitance value Air-variable or trimmer forms

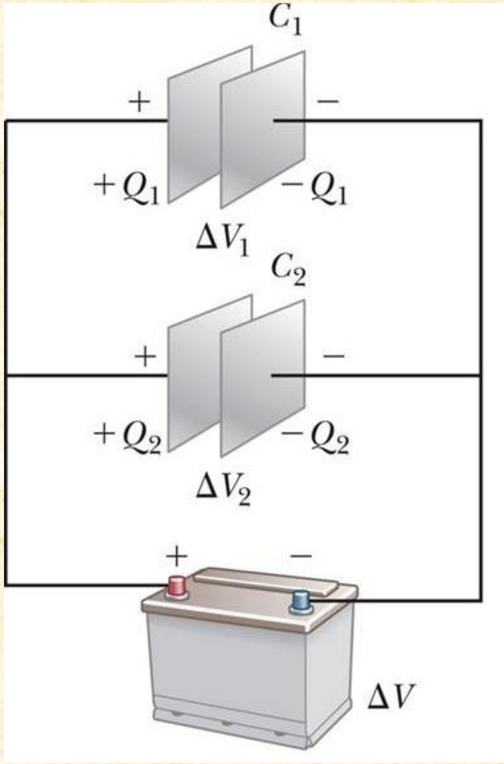




Capacitors in Series and Parallel

Capacitors in parallel

consider a voltage V applied across three capacitors



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

Then the charge on each is

$$Q_1 = C_1 V \qquad Q_2 = C_2 V \qquad Q_3 = C_3 V$$

The total charge Q on the three capacitors is

$$Q_1 + Q_2 + Q_3 = C_1 V + C_2 V + C_3 V$$

$$Q_1 + Q_2 + Q_3 = (C_1 + C_2 + C_3) V$$

$$Q = Q_1 + Q_2 + Q_3 \qquad Q = (C_1 + C_2 + C_3) V$$

$$C = C_1 + C_2 + C_3$$

Capacitors in Series and Parallel

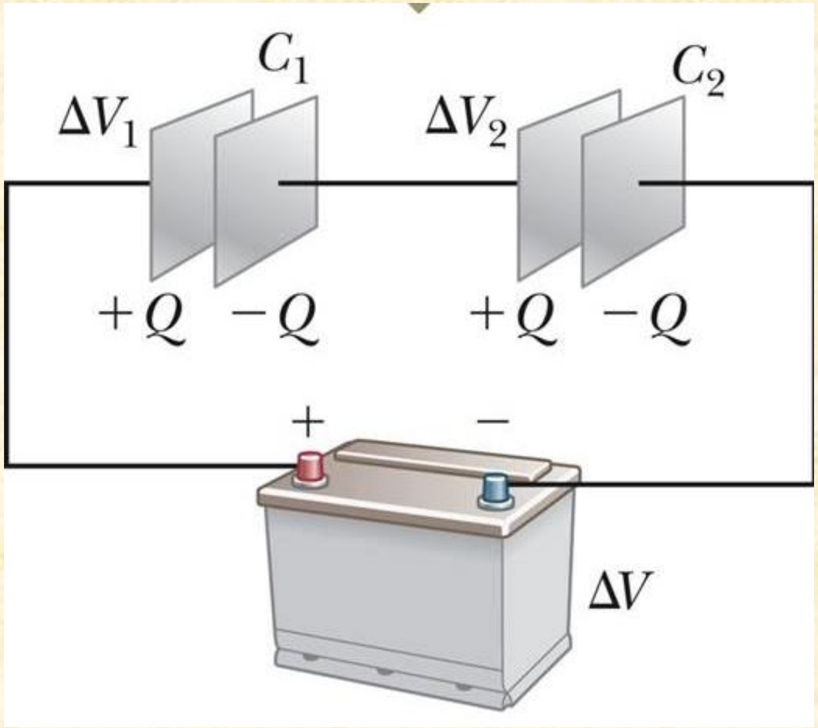
Capacitors in series

$$V_1 = \frac{Q}{C_1} \quad V_2 = \frac{Q}{C_2} \quad V_3 = \frac{Q}{C_3}$$

$$V_1 + V_2 + V_3 = V$$

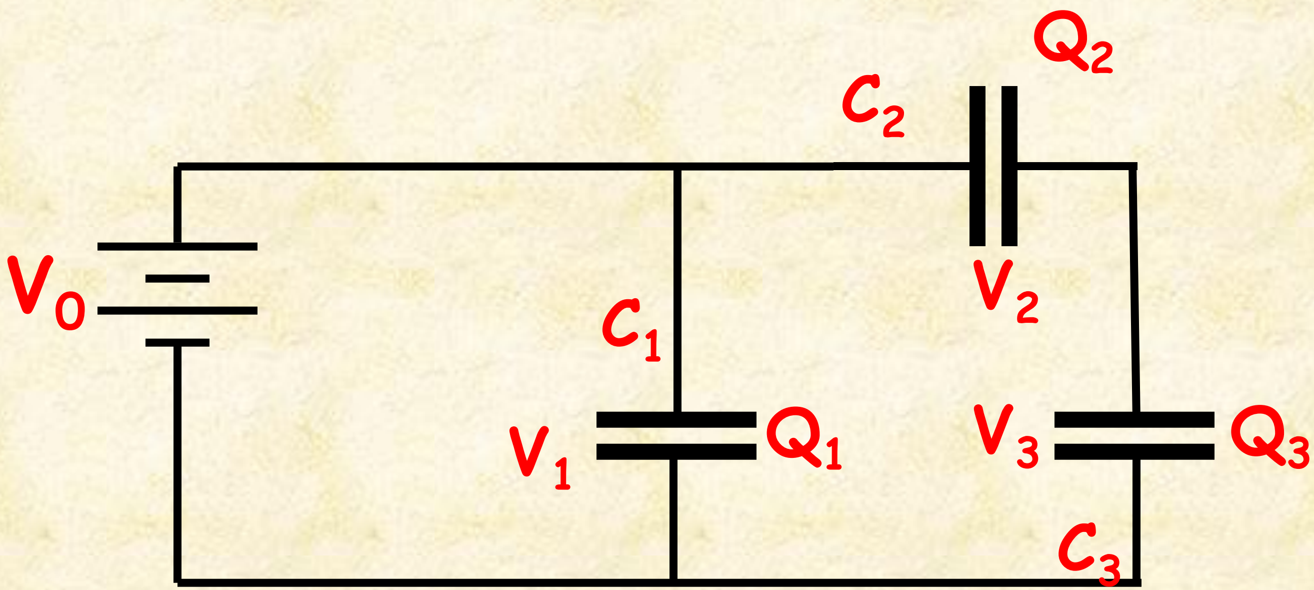
$$V = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

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



Capacitors in Series and Parallel

Which of the following is NOT necessarily true:



A) $V_0 = V_1$

B) $C_{total} > C_1$

C) $V_2 = V_3$

D) $Q_2 = Q_3$

E) $V_1 = V_2 + V_3$

Capacitors in Series and Parallel

A circuit consists of three unequal capacitors C_1, C_2, and C_3 which are connected to a battery of voltage V_0. The capacitance of C_2 is twice that of C_1. The capacitance of C_3 is three times that of C_1. The capacitors obtain charges Q_1, Q_2, and Q_3.

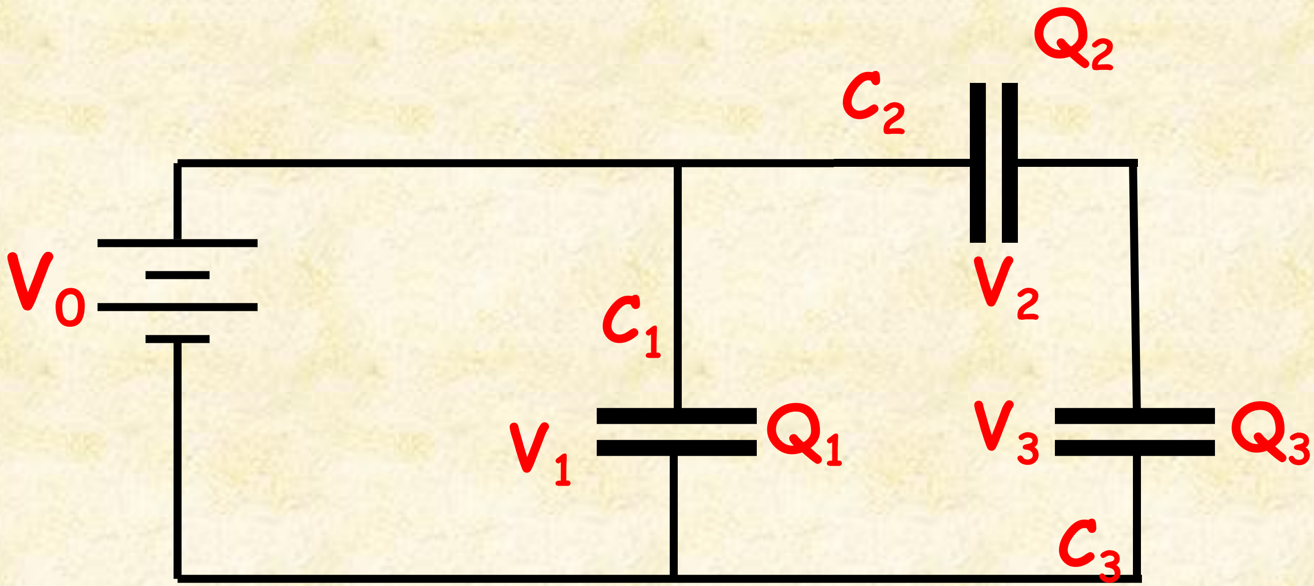
A. $Q_1 > Q_3 > Q_2$

B. $Q_1 > Q_2 > Q_3$

C. $Q_1 > Q_2 = Q_3$

D. $Q_1 = Q_2 = Q_3$

$\boxed{\textbf{E. } Q_1 < Q_2 = Q_3}$



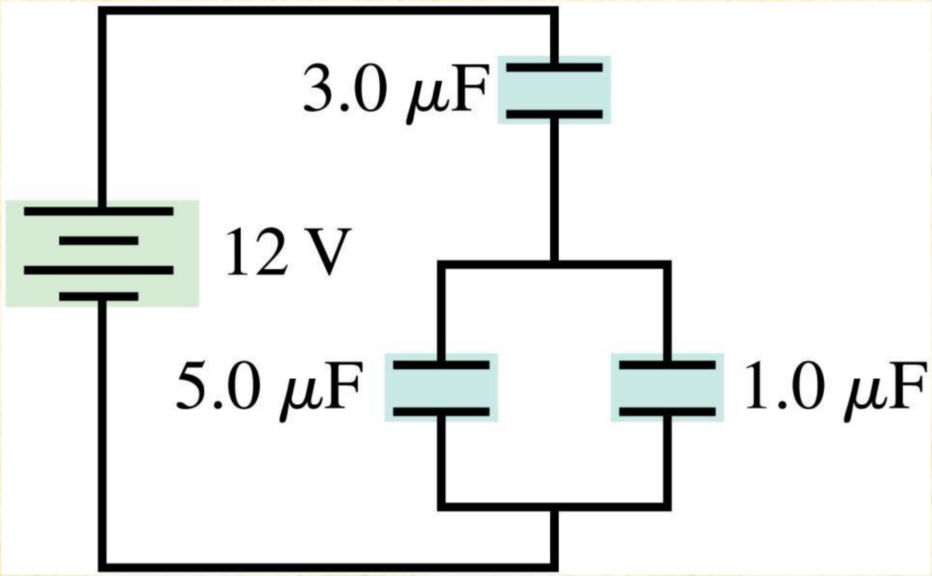
Capacitors in Series and Parallel

Example :

From the circuit shown in the present figure.

a. Find the equivalent capacitance of the combination of capacitors in the circuit.

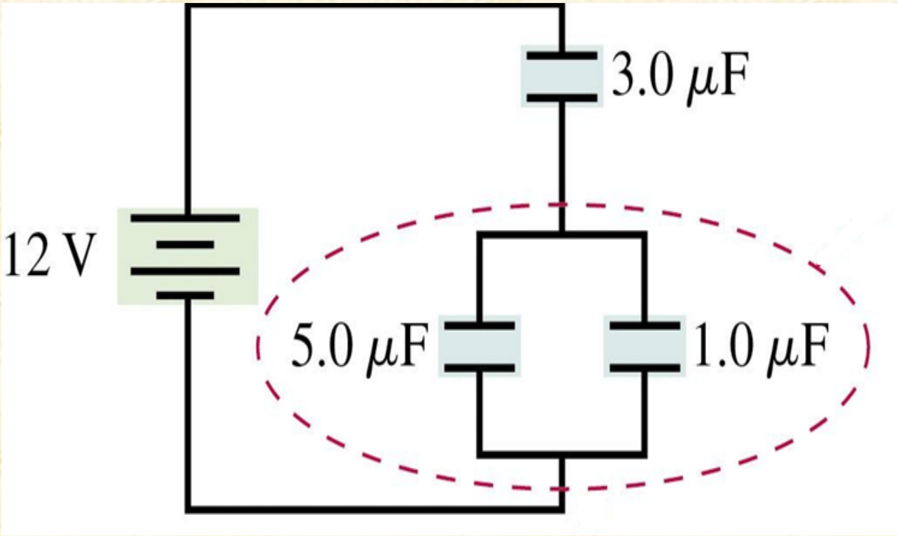
b. What charge flows through the battery as the capacitors are being charged?

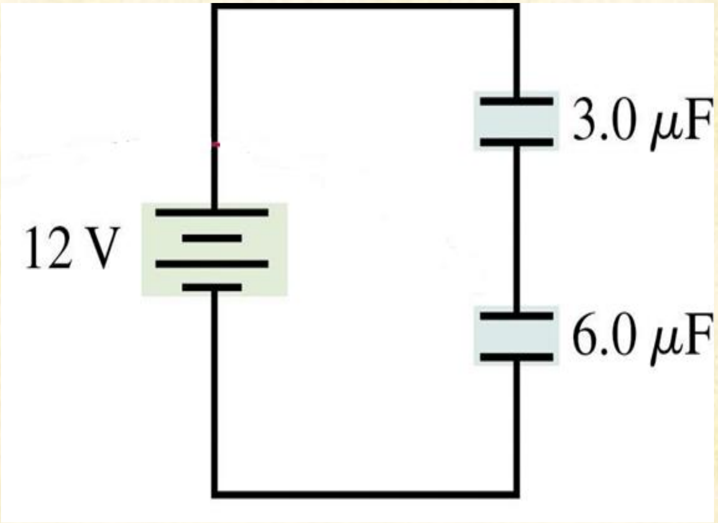


Capacitors in Series and Parallel

Sol.

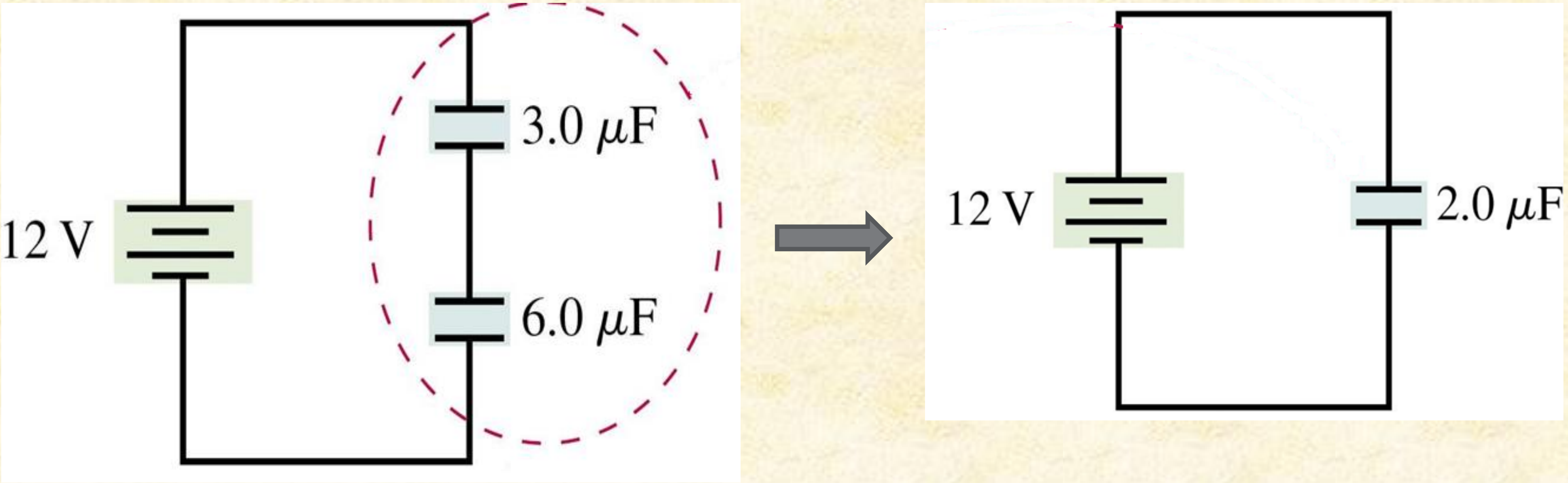
reduce the capacitors to a single equivalent capacitance





$$C_{eq} = 5.0\ \mu\ F + 1.0\ \mu\ F = 6.0\ \mu\ F$$

Capacitors in Series and Parallel



$$\frac{1}{C_{eq}} = \frac{1}{3} + \frac{1}{6} \qquad C_{eq} = 2.0\, \mu\, F$$

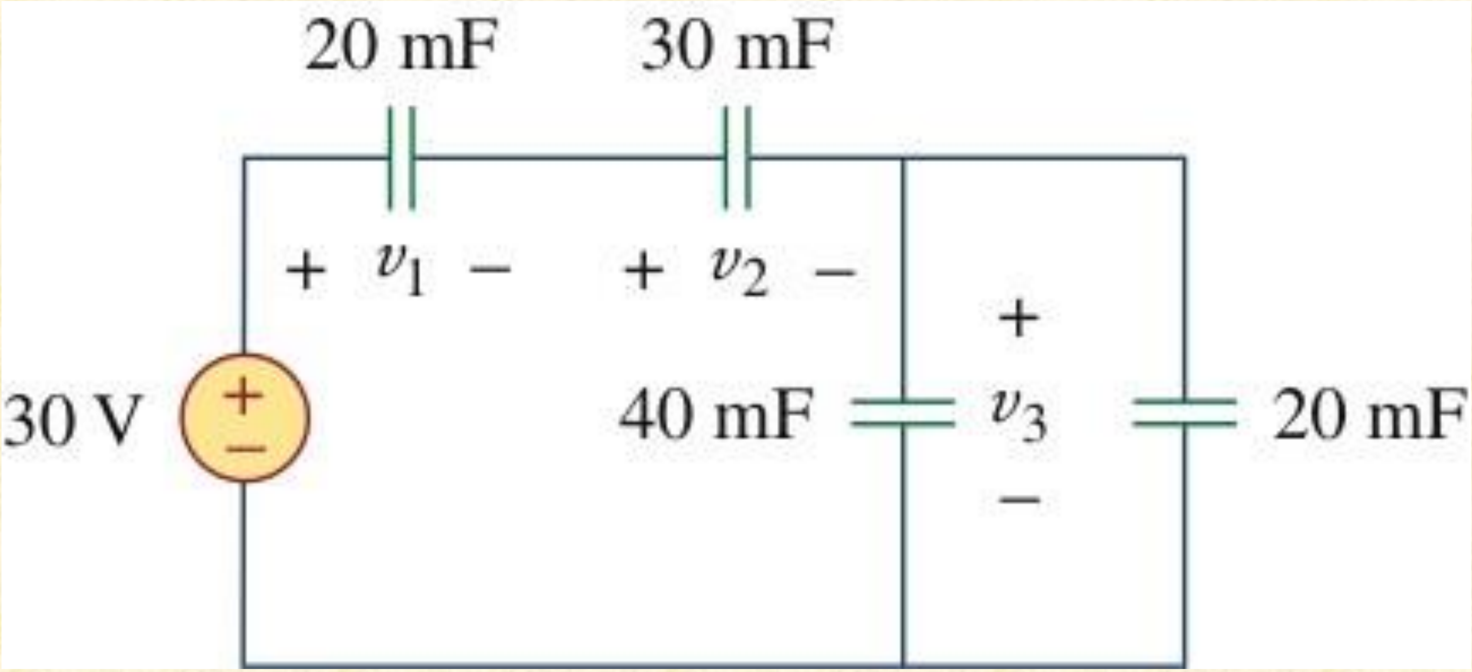
The battery sees a capacitance of 2.0 μF. To establish a potential difference of 12 V, the charge that must flow is

$$Q = C_{eq}\,\Delta V_C = (2.0 \times 10^{-6}\ \mathrm{F})(12\ \mathrm{V}) = 2.4 \times 10^{-5}\ \mathrm{C}$$

Capacitors in Series and Parallel

Example :

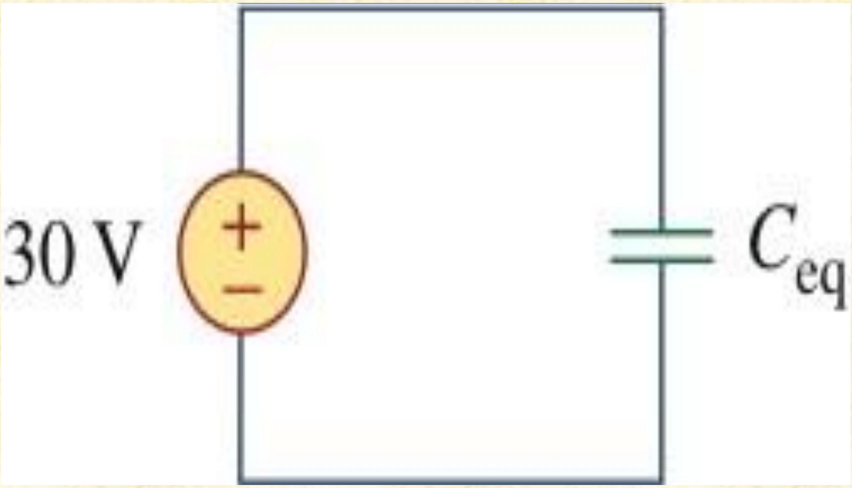
For the circuit in below figure, find the voltage across each capacitor.



Capacitors in Series and Parallel

Sol.

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



Two parallel capacitors:

$$C_{eq1} = 20 + 40 = 60 \text{ mF}$$

$$\therefore C_{eq} = \frac{1}{\frac{1}{60}+\frac{1}{30}+\frac{1}{20}} \text{mF} = 10\text{mF}$$

Total charge

$$q = C_{eq} v = 10 \times 10^{-3} \times 30 = 0.3\text{C}$$

Capacitors in Series and Parallel

Therefore

$$v_1 = \frac{q}{C_1} = \frac{0.3}{20 \times 10^{-3}} = 15\ \text{V}$$

$$v_2 = \frac{q}{C_2} = \frac{0.3}{30 \times 10^{-3}} = 10\ \text{V}$$

Alternatively, since the 40-mF and 20-mF capacitors are in parallel, they have the same voltage v3 and their combined capacitance is 40+20=60mF.

$$v_3 = \frac{q}{60\text{mF}} = \frac{0.3}{60 \times 10^{-3}} = 5\text{V}$$

A capacitor stores energy

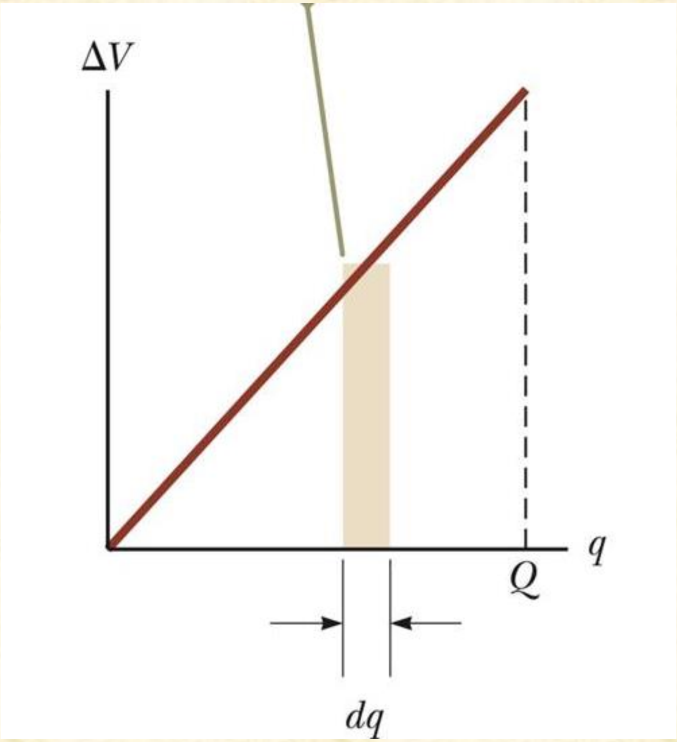
Remember that the voltage V is the work done per unit charge: $V = \dfrac{W}{Q}$

$$dw = \Delta v * dq \qquad \Delta v = q/c$$

$$dw = q/c * dq$$

$$w = \int q/c * dq \qquad w = \frac{q^2}{2c}$$

$$\boxed{w = \frac{1}{2}\,Qv = \frac{1}{2}\,Cv^2}$$



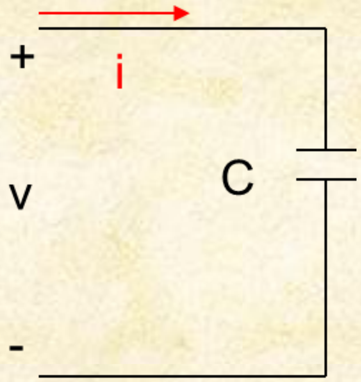
W =the energy stored by the charged capacitor (J)

Q= the charge on the plates (C)

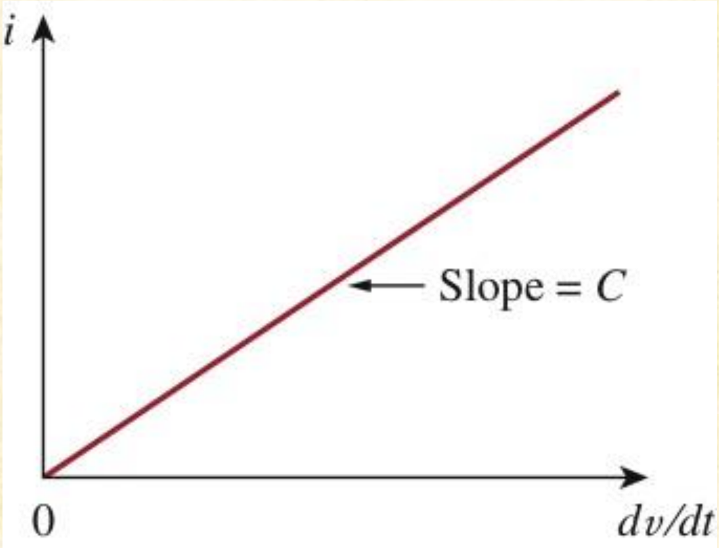
V= the volts across the plates (V)

C = the capacitance of the capacitor (F)

I-V Relation of Capacitor



$$q = Cv, i = \frac{dq}{dt} = C\frac{dv}{dt}$$



- when v is a constant voltage, then i=0; a constant voltage across a capacitor creates no current through the capacitor, the capacitor in this case is the same as an open circuit.
- If v is abruptly changed, then the current will have an infinite value that is practically impossible. Hence, a capacitor is impossible to have an abrupt change in its voltage except an infinite current is applied.

Advantages and disadvantages

Advantages

long life with little degradation and environmental friendly

Very high rate of charge and discharge

Improves safety

Low cost per cycle

Disadvantages

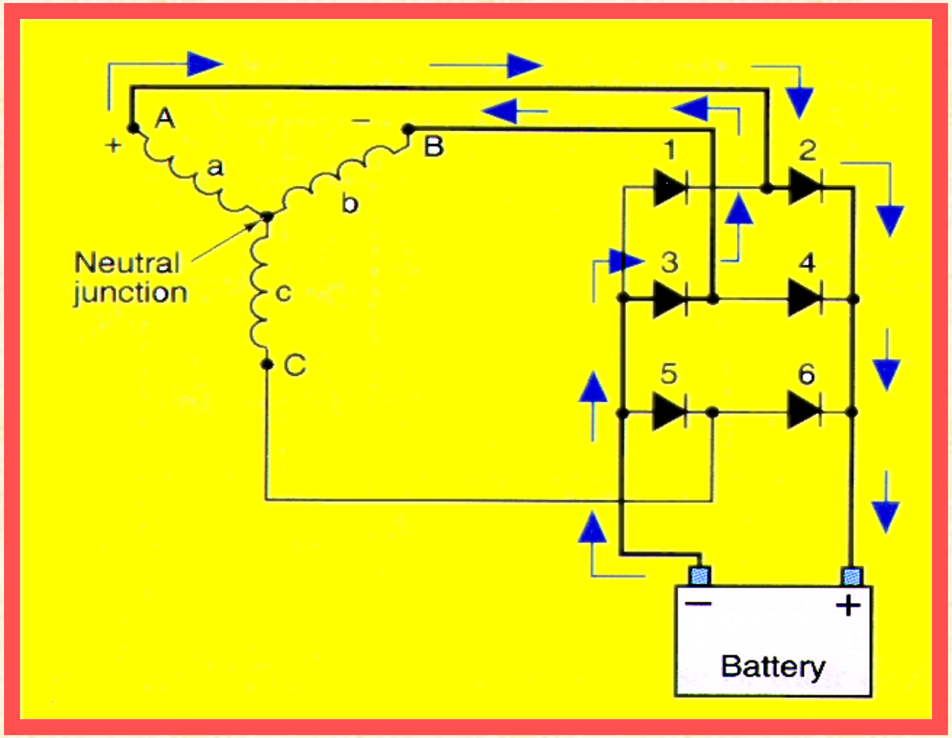
As with any capacitor, the voltage varies with the energy stored. Effective storage and recovery of energy requires complex electronic control and switching equipment, with consequent losses of energy

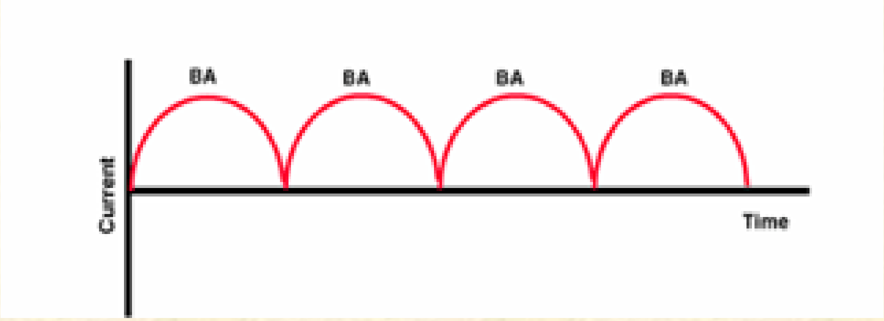
Linear discharge voltage prevents use of the full energy spectrum.

High self-discharge – the rate is considerably higher than that of an electrochemical battery.

Capacitor applications

Alternating voltage and current are not usually desirable for operating equipment

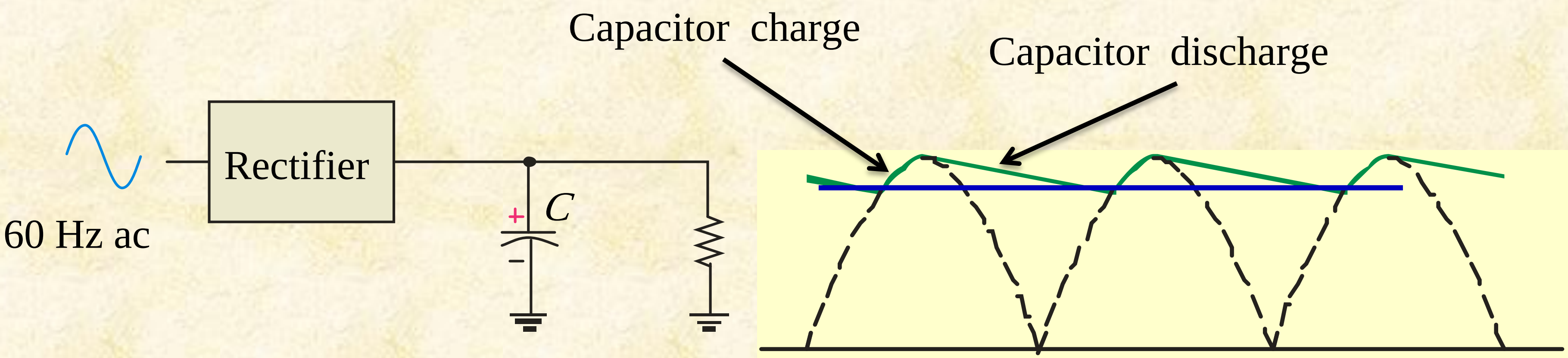


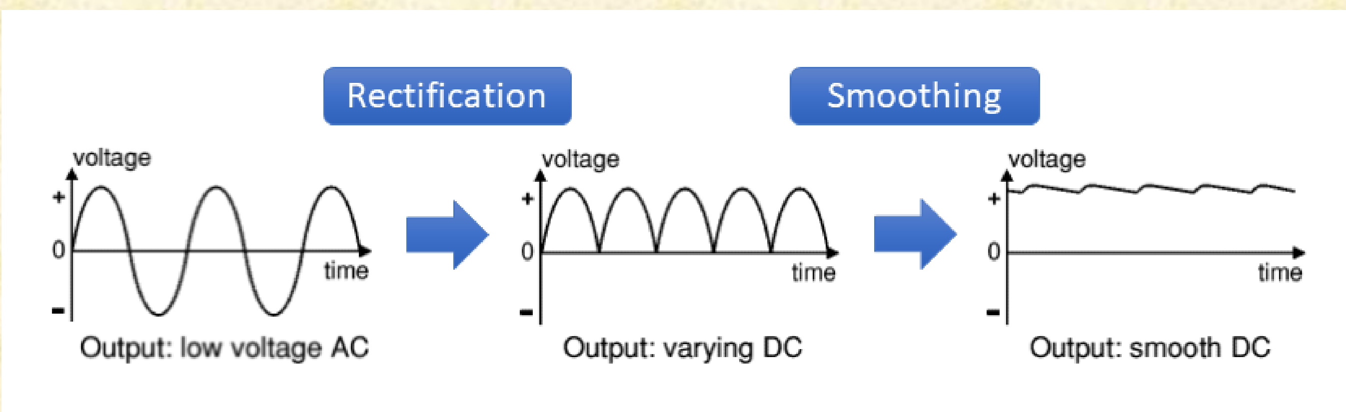


Capacitor applications

Capacitor application in rectifier

A capacitor adds a smoothing effect to the wave by discharging on the down slope of the curve.





Capacitor applications

Primary ignition system