3.B.2 - Capacitance

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Capacitors (Units are Farads: F)

In electric circuits, charges are stored on the parallel plates of devices called capacitors.

Storing charges on parallel plates requires energy, which can be provided by a battery.

Capacitance is defined by charges per voltage:

$C = \dfrac{Q}{\Delta V}$	C = Capacitance (F = C/V) Q = Charge (C) ΔV = Voltage (J/C)

Note: this is an AP equation, but has a different form in the resources: $\Delta V = \dfrac{Q}{C}$

One Farad is really large: often you'll see μF, nF, or pF on real capacitors. Know metric prefixes!

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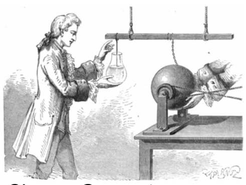
Historical Capacitors

The first charge storage devices were called Leyden Jars, after the town of their invention in 1745.

They consisted of conductors separated by an insulator, with wires attached.



Charge Generator

Demo homemade capacitors - use Van De Graaf generator, and ground Leyden Jar!

Nowadays, capacitors are much smaller and better: Show capacitors.

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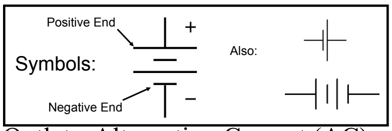
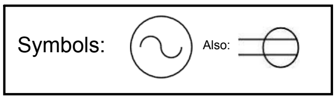
Circuit Components & Symbols 1

Batteries - provide electric potential (voltage) in a direct current (DC) circuit (electrons flow only one way)



Outlet - Alternating Current (AC) (electrons go back and forth at some frequency) voltage supply



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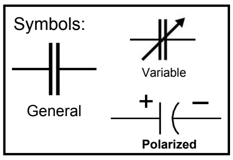
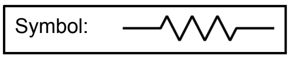
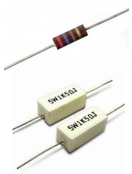
Circuit Components & Symbols 2

Capacitors - store charge.



Resistors - block current flow.





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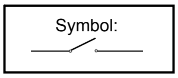
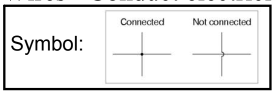
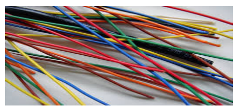
Circuit Components & Symbols 3

Switches - Stop or start electron flow, depending on position (on/off).

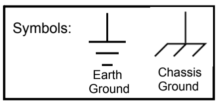


Wires - Conduct electricity.





Ground - Direct connection to the Earth or machine for circuit completion without the need for wires.



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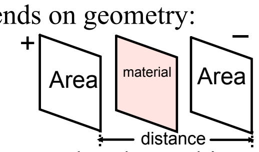
Capacitor Details

An object's capacitance depends on geometry:

- Area of plates,
- Distance between plates,
- Material between plates.



Does not depend on the charge on the plates, this changes depending on conditions.

$C = \kappa\varepsilon_0 \dfrac{A}{d}$	κ = dielectric constant of material (1.0 for now - discussed in 3.B.3) ε_0 = permittivity of free space ($8.85E-12\ C^2/N{\bullet}m^2$) A = area of one plate (m^2) d = separation between plates (m)
AP Equation	

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Capacitor Example

What is the capacitance of an object consisting of two plates with an area of 1.4 E -3 m^2, separated by a distance of 0.50 mm? Assume κ = 1.0.

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

$$= 1.0 \bullet 8.85E-12C^2/N \bullet m^2 \bullet \frac{1.4E-3m^2}{5.0E-4m} = 2.48E-11F$$

Or 24.8 nF.

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Electric Fields in Capacitors

Capacitors rely on opposite charges stored on parallel conductors.

The resulting electric field between the plates can be calculated thusly:

$E = \dfrac{Q}{\varepsilon_0 A}$	E = Electric Field (N/C) Q = Charge (C) ε_0 = permittivity of free space ($8.85E-12\ C^2/N{\bullet}m^2$) A = Area of one plate (m^2)
AP Equation	

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Capacitor Potential Energy (U_c)

Batteries do work, forcing charges onto capacitor plates. Mathematically:

AP Equations	$U_C = \dfrac{1}{2}QV$ $= \dfrac{1}{2}CV^2$	U_c = Energy (J) Q = Charge (C) V = Voltage (Volts: J/C) C = Capacitance (Farads: C/V)
Non-AP Equation	$= \dfrac{1}{2} \bullet \dfrac{Q^2}{C}$	

Note: the 1/2 in all three forms of the equation denote average voltage. As the capacitor charges, it starts out charging at maximum voltage. By the time it's charged, the voltage has dropped to zero (as charges pile up on the plates, they effectively reduce the applied voltage).

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Energy Example:

CLEAR!!

A defibrillator operates by the sudden discharge of a large capacitor operating at 5000V.
300 J of energy is needed to produce a potentially life-saving pulse.
What capacitance is required to produce the pulse?

$$U_C = \frac{1}{2}CV^2$$

$$C = \frac{2 \bullet U_C}{V^2} = \frac{2 \bullet 300J}{(5000V)^2} = 2.4E-5F = 24\mu F$$

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Follow Up Question:

What is the charge on one of the capacitor's plates?

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

$$Q = C \bullet \Delta V = 2.4E-5F \bullet 5000V = 0.12C$$

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AP Question 1.

Two parallel plates separated by distance d are connected to a source of constant voltage. If the distance between the plates is doubled, what happens to the electrical charge on the plates **and** the electrical potential energy stored in the capacitor?

Charge on Plates	**Potential Energy**
a. halved	halved
b. same	halved
c. same	same
d. doubled	halved
e. doubled	same

A. When the plate separation is doubled, the capacitance is halved; therefore, the charge on the plates is halved (constant voltage), and the stored potential energy of the capacitor is halved.

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

$$U_C = \frac{1}{2}CV^2$$

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AP Question 2.

A parallel-plate capacitor has a capacitance of C. If the area of the plates is doubled, while the separation between the plates is halved, the new capacitance will be:

a. 2 C b. 4 C c. C/2 d. C/4 e. C

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Homework

3.B.2 Problems.
Due: Next Class.

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