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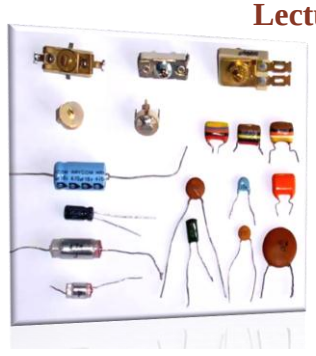
General Physics II

Electrostatic: Principles & Applications

Lecture (13): Capacitors and Capacitance



Dr. Hazem Falah Sakeek

Al-Azhar University of Gaza

Capacitors and Capacitance

Definition of capacitance

Calculation of capacitance

- Parallel plate capacitor
- Cylindrical capacitor
- Spherical capacitor

Combination of capacitors

- Capacitors in parallel
- Capacitors in series

Energy stored in a charged capacitor (in electric field)

Capacitor with dielectric

problems

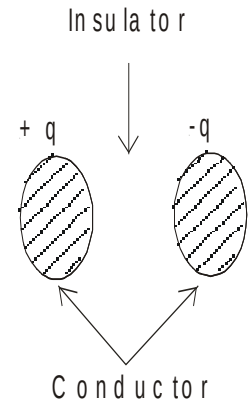
يعتبر هذا الفصل تطبيقاً على المفاهيم الأساسية للكهربية الساكنة، حيث سنركز على التعرف على خصائص المكثفات **Capacitors** وهي من الأجهزة الكهربية التي لا تخلو منها أية دائرة كهربية. ويعد المكثف بمثابة مخزن للطاقة الكهربية. والمكثف عبارة عن موصلين يفصل بينهما مادة عازلة.

Capacitor

A capacitor consists of two conductors separated by an insulator.

The capacitance of the capacitor depends on the geometry of the conductors and on the material separating the charged conductors, called dielectric that is an insulating material.

The two conductors carry equal and opposite charge +*q* and -*q*.

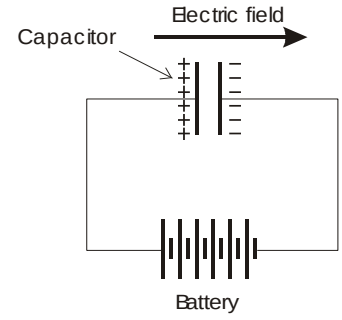


Definition of Capacitance

Definition of Capacitance

The capacitance *C* of a capacitor is defined as the ratio of the magnitude of the charge on either conductor to the magnitude of the potential difference between them as shown in the figure.

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



The capacitance *C* has a unit of *C/v*, which is called *farad F*

$$F = C/v$$

$1\mu F = 10^{-6} F$, $1nF = 10^{-9} F$, $1pF = 10^{-12} F$

The capacitor in the circuit is represented by the symbol shown in the figure

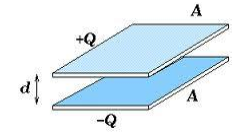
Calculation of Capacitance

The most common type of capacitors are:-

- Parallel-plate capacitor
- Cylindrical capacitor
- Spherical capacitor

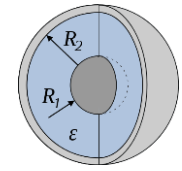
We are going to calculate the capacitance of parallel plate capacitor using the information we learned in the previous chapters and make use of the equation.

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



Parallel-plate capacitor

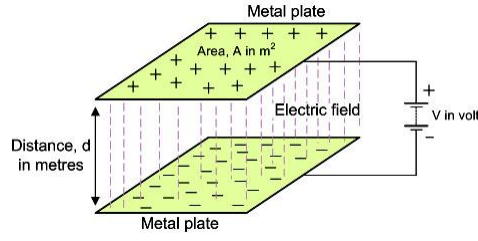
Cylindrical capacitor



Spherical capacitor

Parallel Plate Capacitor

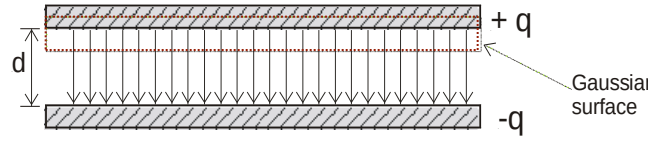
Two parallel plates of equal area *A* are separated by distance *d* as shown in the figure bellow. One plate charged with +*q*, the other -*q*.



The capacitance is given by $C = \frac{q}{V}$

First we need to evaluate the electric field *E* to workout the potential *V*.

Using gauss law to find *E*,



The charge per unit area on either plate is $\sigma = q/A$

$$\therefore E = \frac{\sigma}{\varepsilon_o} = \frac{q}{\varepsilon_o A}$$

The potential difference between the plates is equal to *Ed*, therefore

$$V = Ed = \frac{qd}{\varepsilon_o A}$$

The capacitance is given by

$$C = \frac{q}{V} = \frac{q}{qd/\varepsilon_o A} \longrightarrow \therefore C = \frac{\varepsilon_o A}{d}$$

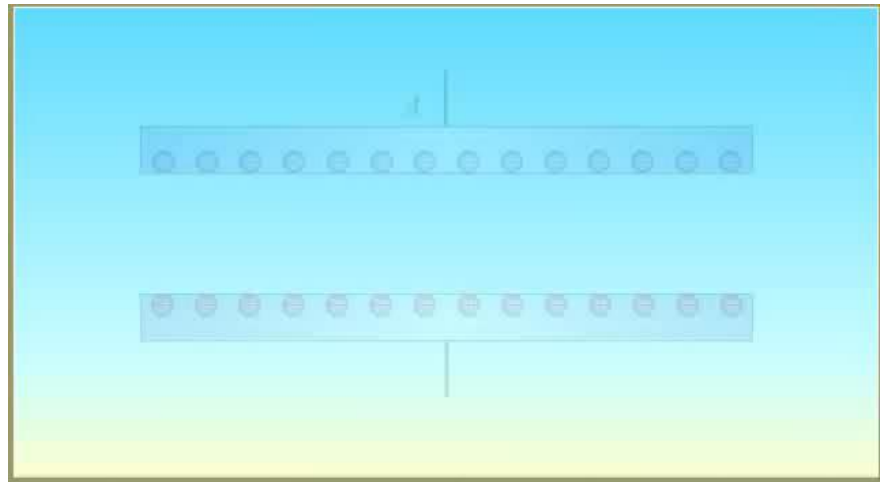
$$\therefore C = \frac{\varepsilon_o A}{d}$$

Notice that the capacitance of the parallel plates capacitor is depends on the geometrical dimensions of the capacitor.

The capacitance is proportional to the area of the plates and inversely proportional to distance between the plates.

تمكننا المعادلة من حساب سعة المكثف من خلال الأبعاد الهندسية له، حيث أن سعة المكثف تتناسب طردياً مع المساحة المشتركة بين اللوحين وعكسياً مع المسافة بين اللوحين.

Parallel Plate Capacitor



A parallel plate capacitor consists of two flat plates of area A separated by a distance d. When each plate is given a charge of magnitude Q.

Example (1)

An air-filled capacitor consists of two plates, each with an area of 7.6cm^2, separated by a distance of 1.8mm. If a 20V potential difference is applied to these plates, calculate,

- the electric field between the plates,
- the surface charge density,
- the capacitance, and
- the charge on each plate.

Solution

(a) $E = \frac{V}{d} = \frac{20}{1.8\times10^{-3}} = 1.11\times10^{4}\, V/m$

(b) $\sigma = \varepsilon_o E = (8.85\times10^{-12})(1.11\times10^{4}) = 9.83\times10^{-8}\, C/m^2$

(c) $C = \frac{\varepsilon_o A}{d} = \frac{(8.85\times10^{-12})(7.6\times10^{-4})}{1.8\times10^{-3}} = 3.74\times10^{-12}\, F$

(d) $q = CV = (3.74\times10^{-12})(20) = 7.48\times10^{-11} C$

Cylindrical Capacitor

In the same way we can calculate the capacitance of cylindrical capacitor, the result is as follow

$$C = \frac{2\pi\varepsilon_o l}{\ln(b/a)}$$

Where *l* is the length of the cylinder, *a* is the radius of the inside cylinder, and *b* the radius of the outer shell cylinder.

Spherical Capacitor

In the same way we can calculate the capacitance of spherical capacitor, the result is as follow

$$C = \frac{4\pi\varepsilon_o ab}{b-a}$$

Where *a* is the radius of the inside sphere, and *b* is the radius of the outer shell sphere.

Example (2)

An air-filled spherical capacitor is constructed with inner and outer shell radii of 7 and 14cm, respectively. Calculate,

- The capacitance of the device,
- What potential difference between the spheres will result in a charge of 4μC on each conductor?

Solution

(a) $C = \dfrac{4\pi\varepsilon_o ab}{b-a} = \dfrac{(4\pi \times 8.85\times10^{-12})(0.07)(0.14)}{(0.14-0.07)} = 1.56\times10^{-11}F$

(b) $V = \dfrac{q}{C} = \dfrac{4\times10^{-6}}{1.56\times10^{-11}} = 2.56\times10^{5}V$

Problem to solve by your self

A parallel-plate capacitor has circular plates of 8.0cm radius and 1.0mm separation. What charge will appear on the plates if a potential difference of 100V is applied?