Electricity and Magnetism

Lecture Six

Capacitance

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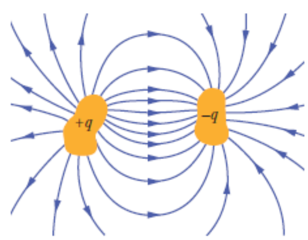
1. Capacitance

The capacitor, a device in which electrical energy can be stored. For example, the **batteries in a camera** store energy in the photoflash unit by charging a capacitor.

Figure 1 shows some of the many sizes and shapes of capacitors. Figure 2 shows **the basic elements of any capacitor—two isolated conductors of any shape**. No matter what their geometry, flat or not, we call these **conductors plates**.

Figure 25-3a shows a parallel-plate capacitor, consisting of two parallel conducting plates of area A separated by a distance d. The symbol we use to represent a capacitor (⊣⊢).



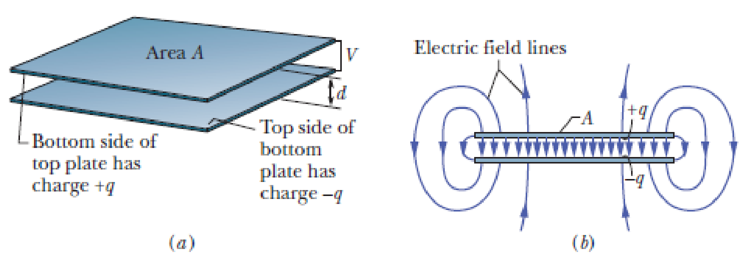


Figure 1: An assortment of capacitors. Two conductors, isolated electrically from each other. (a) A parallel-plate capacitor, (b) As the field lines show

When a capacitor is charged, its plates have charges of equal magnitudes but opposite signs: +q and -q.

The charge q and the potential difference V for a capacitor are proportional to each other; that is:

$$q = CV.$$

The proportionality constant C is called the capacitance of the capacitor.

The SI unit of capacitance is the **coulomb per volt**.

This unit occurs so often that it is given a special name, the **farad (F)**:

1 farad = 1 F = 1 coulomb per volt = 1 C/V.

2. Calculating the Capacitance

To calculating the capacitance (C): (1) Assume a charge q on the plates; (2) calculate the electric field between the plates, using Gauss' law; (3) calculate the potential difference V between the plates.

$$\varepsilon_0 \oint \vec{E} \cdot d\vec{A} = q.$$

$$q = \varepsilon_0 E A$$

$$V_f - V_i = -\int_i^f \vec{E} \cdot d\vec{s},$$

Letting V represent the difference V_f - V_i:

$$V = \int_-^+ E\, ds$$

$$V = \int_{-}^{+} E\, ds = E \int_{0}^{d} ds = Ed.$$

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

$$C = \frac{\varepsilon_0 A}{d} \quad \text{(parallel-plate capacitor).}$$

Example: Find the capacitance for the parallel plates of area A = 0.5 m^2 separated by a distance d = 10 cm?

Solution:

$$C = \frac{\varepsilon_0 A}{d} = \frac{8.85 \times 10^{-12} \times 0.5}{0.1} = 44.25 \times 10^{-12} F$$

3. Energy Stored in an Electric Field

The energy is stored in the electrical field in the space between the capacitor plates. It depends on the amount of electrical charge on the plates and on the potential difference between the plates. The work required to bring the total capacitor charge up to a final value q, this work is stored as potential energy U in the capacitor:

$$U = \tfrac{1}{2} C V^2 \quad \text{(potential energy).}$$

The potential energy of a charged capacitor may be viewed as being stored in the electric field between its plates.

Example: An capacitor plates has a capacitance C = 1.25 F, how much potential energy is stored in the capacitor plates when potential difference between the plates V= 5mv?

Solution:

$$U = \frac{1}{2}\, C\, V^2 = \frac{1}{2} \times 1.25 \times 5 \times 10^{-3} = 3.125 \times 10^{-3}\, J$$

4. Capacitor with a Dielectric

If you fill the space between the plates of a capacitor with a **dielectric**, which is an insulating material such as mineral **oil or plastic**, what happens to the capacitance?

Michael Faraday first looked into this matter in 1837. Using simple equipment much like that shown in Fig. 25-12, he found that **the capacitance increased** by a **numerical factor k**, which he called the **dielectric constant k** of the insulating material.

$$C = k\, C_{air}$$

where C_{air} is the capacitance with **only air** between the plates and C is the capacitance with **dielectric** between the plates.

5. Dielectrics: An Atomic View

What happens, in atomic and molecular terms, when we put a dielectric in an electric field? There are two possibilities, depending on the type of molecule:

1. Polar dielectrics. The molecules of some dielectrics, like water, have permanent electric dipole moments. In such materials (called polar dielectrics), the electric dipoles tend to line up with an external electric

field. The alignment of the electric dipoles produces an electric field that is directed opposite the applied field and is smaller in magnitude.

2. Nonpolar dielectrics. Regardless of whether they have permanent electric dipole moments, molecules acquire dipole moments by induction when placed in an external electric field. we saw that this occurs because the external field tends to “stretch” the molecules, slightly separating the centers of negative and positive charge.

6. Refrences

Walker, Jearl, Robert Resnick, and David Halliday. Halliday and resnick fundamentals of physics. Wiley, 2014.